Effects of phonetic and linguistic factors on auditory processing: evidence from aphasic and normal listeners

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Submitted for the Doctor of Philosophy examination

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University College London

2004

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Abstract

The mapping of acoustic speech signals onto linguistic representations is highly complex, and a number of competing models of both system architecture and auditory processing mechanisms have been proposed. Detailed investigation of processing in both normal and aphasic listeners provides insights into the nature of the underlying processing mechanisms, and can be used to test the empirical validity of theoretical models. Three related experiments were designed to explore aspects of the complex interrelations between phonetic, lexical and semantic levels of representation in the auditory speech processing of five adults with chronic aphasia and ten controls. The first experiment explored whether the effects of word frequency and imageability that affect recognition of words heard in isolation exert the same influence when words are heard in the context of a meaningful sentence. The second experiment compared discrimination of voice, place and manner contrasts in nonword and word minimal pairs, to explore the effect of the lexical status of the carrier syllable on phonological encoding. The third experiment used a picture-word verification task to explore the effects of semantic contexts provided by pictures on discrimination. Stimuli were closely matched across experiments two and three to allow detailed comparison of lexical and semantic influences on processing. Accuracy and reaction time data were collected, with control group data indicating normal patterns of performance. Aphasic data were analysed mainly as a series of single cases, and interpreted in the light of each individual's performance on a range of language processing assessments. The results revealed a number of different patterns in the effects of linguistic context for control and aphasic listeners, with aphasic listeners showing greater influences of lexical and semantic contexts on processing. The results of all three experiments are discussed in relation to competing theoretical models of auditory processing. It is argued that a distributed connectionist model currently accounts for the data more effectively than either localist connectionist or cognitive neuropsychological models.

Acknowledgements

The work presented in this thesis was made possible by the support of a large number of individuals and organisations. I would like to express my particular gratitude to AL, JW, JWh, TDS and TVR for giving so willingly of their time and providing many insights into their aphasia; to all the participants who took part in the control group; to Professor Stuart Rosen and Maria Black of University College London, for guidance and supervision; to the speech and language therapists who referred participants to the study; to JCW for patience and humour; to AW for support; and to ADW for instilling an appreciation of words.

This research was supported by a Postgraduate Studentship Award from the Engineering and Physical Sciences Research Council (award number: 98319717).

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Chapter 1 Review of auditory speech processing in normal and aphasic listeners

Introduction

> "*When context restricts the plausible interpretation of an utterance, minimal acoustic processing may be required.*" (Lesser & Milroy 1993 p. 63)

The processes involved in mapping from acoustic speech signals onto representations of word forms and meanings are highly complex. Research suggests that auditory language processing involves a number of processing modules, such as an acoustic-phonetic processor, an auditory input lexicon and a lexical semantic system. The precise nature of the representations within each of these modules, and the processes that map information between them, have been the source of debate for many decades.

Auditory processing disorders are a common feature of aphasia, although in clinical practice they may frequently be overlooked or underestimated (McClenahan, Johnston, & Densham 1992). In the research literature too, less attention has been paid to the treatment of auditory processing compared with other aspects of language impairment in aphasia (Taylor-Goh (Ed) 2004; Whitworth, Webster, & Howard 2004). This seems an injustice to the many people who face the consequences of impaired auditory comprehension in their daily lives. Even in mild aphasia, impairments of auditory processing can affect both emotional well-being and social participation (Le Dorze et al. 1996), while more severe comprehension difficulties can profoundly affect functional communication, self-esteem and autonomy (Taylor-Goh (Ed) 2004).

In this chapter, an overview of auditory processing disorders in aphasia will be given, and the key levels of processing involved in mapping from the acoustic signal to the forms and meanings of words will be considered. Evidence from the literature will be presented to demonstrate how these aspects of processing manifest in normal listeners, and how they may be impaired in aphasia. A main focus of this study will be the extent to which higher level representations might modify phonological encoding and spoken word recognition. Therefore, evidence from the literature related to the top-down flow of information at each of these processing levels will be considered. Alternative theoretical approaches to understanding the auditory processing of speech will be introduced, and several key theoretical questions will be identified.

Overview of auditory processing disorders in aphasia

In a seminal paper, Franklin presented nine cases of individuals with fluent aphasia who had deficits in auditory processing (Franklin 1989). Her methods of assessment and interpretation of the results were underpinned by a cognitive neuropsychological account of language processing. Through the use of tests that differentially assessed components of the auditory processing system, she demonstrated that syndrome-based accounts of impairment were unable to capture several dissociations between components. The tests she employed included phoneme discrimination, auditory lexical decision, auditory synonym matching, word repetition and nonword repetition. While some patients showed deficits in phoneme discrimination, others were impaired particularly in the spoken word recognition[1] or comprehension tasks. These three patterns were described as word-sound deafness, word-form deafness and word-meaning deafness respectively. Each of these aspects of processing in both normal and aphasic listeners will be examined further below.

It has been claimed that auditory comprehension deficits in aphasia are directly attributable to difficulties with discrimination of either acoustic cues (Carpenter & Rutherford 1973) or phonemes (Luria 1966). However, there is now considerable

[1] The term 'spoken word recognition' is used to refer to the recognition of phonological word-forms, and is distinct from the comprehension of word-meanings.

evidence that the relationship between discrimination and comprehension is much more complex than this. A severe deficit in speech discrimination does not necessarily result in a severe impairment of word recognition or comprehension, while word recognition and comprehension may be very impaired despite normal speech perception. Evidence related to these dissociations will be presented below. It is perhaps unsurprising that such dissociations should have been found, given the wide range of linguistic and conceptual variables that are now known to influence comprehension abilities.

Nevertheless, the fact that comprehension may be relatively spared in the presence of a speech perception deficit does raise questions as to the validity of theoretical models that propose purely serial auditory processing mechanisms. This issue will be considered in more depth later. First we will consider the role of early auditory perceptual processing, then the processes involved in phonological encoding and spoken word recognition, and finally some aspects of spoken word comprehension. Although these levels of processing are discussed separately, it should be noted that they are not entirely separable in studies that use meaningful words as stimuli. For instance, a study that explores phoneme discrimination using word minimal pairs will involve word recognition and comprehension processes, whilst a study that focuses on spoken word recognition will also involve phonological encoding. In this chapter, studies have been grouped according to the level of processing that forms the main focus of enquiry.

The first sets of studies that will be considered are those that relate to early auditory perceptual processing and to phonological encoding. Impairments at either of these levels may contribute to patterns of performance that have variously been described as auditory verbal agnosia, word-sound deafness, pure word deafness, and word deafness. These terms are sometimes used interchangeably as if they describe a distinct syndrome, although detailed case studies demonstrate considerable variation between individuals given the 'same' diagnosis. One important aspect of variation relates to laterality of the lesion/s. In at least two thirds of cases, lesions affect bilateral temporal lobes, while the remaining cases mainly result from unilateral left temporal lesions (Poeppel 2001 p.683-4). Poeppel points out that, where the deficit arises from a unilateral lesion, this often involves the subcortical structures that connect right to left auditory cortex, thus even unilateral cases of pure word deafness typically involve both hemispheres. In those cases where pure word deafness arises from a unilateral cortical lesion, large areas of cortex are usually damaged and aspects of language comprehension beyond speech perception are impaired.

A further source of variation relates to whether processing of non-speech as well as speech sounds is impaired. In two related disorders, cortical deafness and auditory agnosia, the processing of non-speech sounds is impaired. In cortical deafness there is a severe deficit in the perception and recognition of all acoustic signals, despite normal peripheral hearing mechanisms and (in its pure form) normal language processing (Poeppel p.682). Thus in cortical deafness, the deficit in speech perception can be considered secondary to a more generalised auditory processing deficit and will not be discussed further in this thesis. In auditory agnosia, the recognition of environmental sounds is impaired. Auditory agnosia may co-exist with pure word deafness, but evidence will be presented below that the two types of deficit are at least partially dissociable. Poeppel defined pure word deafness as a syndrome in which speech comprehension is dramatically impaired, while early auditory processing is intact. However, he acknowledged that truly 'pure' cases are rare, since some degree of deficit in pre-speech auditory processing is usually present. Auerbach et al (1982) proposed that there are two subtypes of pure word deafness, depending on whether the disorder arises from unilateral or bilateral lesions. They suggested that bilateral lesions result in prephonetic auditory processing difficulties, while left unilateral lesions specifically affect phoneme discrimination. As Praamstra (1991 p.1217) points out, most reported cases present insufficient data to adequately distinguish between purely phonetic perceptual deficits and those that also implicate aspects of early auditory processing. Evidence related to pre-phonetic auditory processing will be considered further below.

Even within the speech perception deficit, there is variation in which aspects of perception are impaired. Poeppel (2001 p.683) compared performance on a range of phonetic discrimination tasks in six published cases of pure word deafness. He found no common pattern in terms of whether the deficit affected mainly discrimination of place or of voicing contrasts in consonants, of Voice Onset Time continua, or of vowel contrasts. These differences will be considered in more depth later, and related to possible hemispheric differences in early auditory processing.

Reported cases of word-sound deafness also differ in whether individuals present with other aphasic deficits in addition to the speech perception deficit. Best & Howard (1994 p.223) defined pure word deafness as 'impaired speech perception in the context of good speech production, reading and writing', while Poeppel (p.681) similarly stated that written language comprehension, spoken output and written output remain intact. A number of authors have acknowledged that cases of pure word deafness according to these definitions are rare, since the speech perception deficit often accompanies other aphasic symptoms (e.g. Praamstra 1991 p.1197). Kazui et al (1990 p.485) extensively reviewed published cases and found that most patients presenting with 'cerebral auditory disorders' had some aphasic symptoms in addition to the speech perception deficit. In recognition of the rarity of 'pure' cases, Buchman et al (1986 p.498) defined word deafness in terms of 'a disparity between auditory verbal comprehension and other linguistic functions'.

It appears that there is currently insufficient agreement about terms such as pure word deafness and word deafness for these to be used as diagnostic categories without also considering individual performance across a range of tasks in some detail. Nevertheless, such terms are useful in identifying those individuals for whom a difficulty in auditory speech perception is the primary clinical manifestation of neurological damage. We shall now consider further evidence related to the nature of auditory processing difficulties in aphasia.

Early Auditory Perceptual Processing

An association has been demonstrated between speech discrimination impairments and difficulties with pre-linguistic auditory processing in some cases of aphasia. Although deficits in early auditory processing are rarely considered in clinical assessment of aphasia, they are of significance since such deficits may limit the information available to the speech perception and comprehension systems. The types of deficit that have been reported fall into two main categories, according to the aspects of processing affected: environmental sound recognition, and the extraction of acoustic cues from the auditory signal. These will be considered in turn.

Environmental sound recognition

Some evidence that the auditory processing difficulties of aphasic listeners are not restricted to the processing of speech comes from studies that examine the discrimination and recognition of non-speech environmental sounds. These are typically familiar sounds that are easy to discriminate, such as a telephone ringing, a dog barking, or the sound of running water. For example, Ammon showed that some brain-damaged patients had auditory agnosia, or difficulty in recognising environmental sounds (Ammon 1979). Eighty-one patients with either left or right hemisphere lesions were tested on recognition of meaningful environmental sounds, with stimuli presented for either five or fifteen seconds. Overall there was a correlation between performance on this task and on a test of non-verbal intelligence. In addition, the aphasic patients showed difficulties in recognising environmental sounds that were presented for the shorter duration. This was claimed to demonstrate a general slowing down of auditory recognition processes in aphasia, which might underlie disturbances of auditory comprehension.

Of course, the type of processing involved in discriminating environmental sounds is of a very different order to that required for discriminating the brief and acoustically subtle differences between similar phonemes. The suggestion that poor discrimination of environmental sounds is directly related to speech perception difficulties in aphasia is undermined by another study (Varney 1984). Varney investigated auditory processing in ninety stroke patients with left hemisphere lesions, of whom eighty were aphasic. Testing of auditory processing was carried out at five to fifteen days post onset, and included both environmental sound recognition and phoneme discrimination. While all of the non-aphasic participants performed normally, almost a third of the aphasic participants made errors on environmental sound recognition. However, the relationship between this impairment and difficulties in speech perception was not straightforward. Nine of the twenty-three patients with impaired environmental sound discrimination demonstrated normal phoneme discrimination, and six of the fourteen patients with impaired phoneme discrimination had normal environmental sound discrimination. Other authors (including Morris, Franklin, Ellis, Turner & Bailey 1996) have also demonstrated dissociations between the recognition of environmental sounds and phoneme discrimination in aphasia.

The reason for this double dissociation may lie not only in differences of acoustic complexity, but also in anatomical differences. Evidence of brain regions involved in the processing of speech/complex non-speech and environmental sounds has been reviewed by Mendez & Geehan (1988). These authors argue that the complex temporal analysis required for speech perception must be carried out by the primary auditory cortex, whereas analysis of most environmental sounds can take place in secondary auditory association areas (p.7). Thus lesions in the respective areas might differentially disturb these two types of processing. This suggests that co-occurrence of environmental sound and speech perception difficulties would arise from lesions extending into both auditory regions, rather than reflecting any causative relationship between the two types of disorder. In any case, the double dissociation shown experimentally indicates that testing the discrimination of environmental sounds, whilst perhaps functionally important, does not provide clear insights into the nature of aphasic speech perception.

Extraction of acoustic cues from the auditory signal

Of greater relevance than environmental sound recognition is the evidence related to extraction of acoustic-phonetic features from the input signal. Although many investigations of higher level auditory processes make little reference to the acoustic signal, it is important to consider the nature of the information available to the cortical auditory systems in order to understand their operation. Before the acoustic signal can be mapped onto linguistic representations, preliminary stages of processing must identify the acoustic features that form the basis of phonetic categories. The main features that define the acoustic signal are its spectral dynamics, amplitude dynamics and periodicity/aperiodicity (O'Connor 1973). Acoustic analysis commences with spectral analysis of the speech signal by the cochlear filter bank. The amplitude of the signal within each narrow frequency range (represented by a small group of inner and outer hair cells) is transmitted via the afferent auditory nerves, across several intermediate synapses, to the bilateral auditory cortex. Here the afferent nerves synapse with tonographically organised neurons; that is, neurons that are anatomically structured according to the sound frequency that they respond to. Responses at both cochlear and cortical synapses maintain information about the various acoustic features in the signal (Geisler 1998b). Thus the input to cortical areas is defined by its resolution of these key acoustic features[2].

It is currently debated whether the auditory cortices of left and right hemispheres respond in different manners to the pre-linguistic acoustic signal. In a comparison of hemispheric responses to speech and complex non-speech stimuli using positron emission tomography (PET), Mummery, Ashburner, Scott & Wise (1999) found no significant differences in the response of left and right auditory cortices to non-speech stimuli. However, dichotic listening tests (in which different auditory stimuli are presented simultaneously to right and left ears) have been used to explore hemispheric asymmetries in very early stages of auditory processing. While both ears/hemispheres are able to process temporal and spectral features in the acoustic signal, there may be differences in the degree to which they carry out these functions (Divenyi & Robinson 1989). In normal right-handed adults, the right ear/left hemisphere has been claimed to be dominant for temporal processing, while the left ear/right hemisphere may be more dominant for pitch perception. For instance, Zatorre & Belin (2001) used PET to identify cerebral regions involved in processing of temporal and spectral acoustic features. They found that both types of feature were processed bilaterally, with primary auditory cortex responding to temporal

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[2] The auditory input in fact undergoes a number of complex transformations, resulting in a non-linear response by the primary auditory cortex to the acoustic signal. See Geisler (1998b) for further discussion.

variation and anterior superior temporal areas responding to spectral variation. However, they found some asymmetry in that responses to temporal features were weighted towards the left hemisphere, while responses to spectral features were weighted towards the right. The authors suggested that this indicated finer resolution of temporal processing in the left hemisphere and of spectral processing in the right hemisphere.

The suggestion that there are hemispheric differences in the processing of spectral and temporal acoustic cues may be important in relation to the processing of phonetic contrasts in speech. Dichotic listening tests on normal listeners have revealed a right-ear advantage for the phonetic feature of voicing (which is primarily based on temporal contrasts), whereas a left-ear advantage has been demonstrated for the feature of place of articulation (which is primarily based on spectral contrasts) (Divenyi & Efron 1979). This suggests that damage to the left hemisphere could result in particular difficulty with discriminating temporal acoustic cues and phonetic voicing contrasts.

A number of studies have shown that aphasic listeners show greater difficulty in the processing of acoustic features than either controls or non-aphasic brain-injured listeners. However, there is conflicting evidence as to whether they are more impaired in the extraction of temporal or spectral information from the acoustic signal. For instance, some aphasic listeners have difficulty detecting spectral acoustic cues such as consonantal burst spectrum, and the direction of formant transitions (Carpenter & Rutherford 1973). This study revealed that aphasic listeners were more successful in discriminating temporal acoustic cues (such as stop-gap duration) than spectral cues. An implication of this finding is that aphasic listeners should find phoneme contrasts more difficult to discriminate if they are based primarily on spectral differences (such as place of articulation) than temporal differences (such as voice onset time). This appears to contradict claims of a right hemisphere advantage for spectral cues, since in most aphasic listeners the right hemisphere is undamaged.

However, it has also been shown that some aphasic listeners are impaired in temporal auditory processing. Auditory temporal order judgement, in which listeners hear two clicks presented consecutively and binaurally, has been tested in listeners with fluent and non-fluent aphasia (von Steinbuchel, Wittmann, Strasburger & Szelag 1999). Participants were asked to indicate the order in which they heard two stimuli. While the non-fluent aphasics' performance was similar to controls, those with fluent aphasia/posterior lesions required increased inter-stimulus intervals to correctly identify the temporal order. Milner has shown that patients with left hemisphere lesions are more likely than either controls or patients with right hemisphere lesions to have difficulty with temporal processing such as gap detection (Milner 1962). Those with left hemisphere damage required longer gaps between clicks in order to identify them as separate events. Auerbach and colleagues (1982) have presented similar evidence of slowed auditory processing in gap detection in a patient with word-sound deafness and amusia.

Further evidence of a temporal processing impairment in aphasia comes from the work of Tallal & Newcombe (1978), who explored the abilities of patients with focal injuries to either the left or right cerebral hemisphere to discriminate complex tones, steady-state vowels, and synthetic CV syllables. They demonstrated that patients with injuries to the left hemisphere showed difficulty in processing rapid acoustic signals in both complex tones and synthetic syllables. They claimed that these patients' speech perception deficits were due to slow pre-linguistic auditory processing, and that this also caused their problems with auditory comprehension. However, this claim has been challenged by a number of authors. For instance, it has been shown that extending formant transitions does not necessarily improve aphasic discrimination of place contrasts (Blumstein et al. 1984; Riedel & Studdert-Kennedy 1985), and that slowing presentation of spoken sentences does not necessarily improve comprehension (Blumstein et al. 1985).

Based on evidence of impaired processing of temporal acoustic features, it might be predicted that aphasic listeners with left hemisphere lesions should be more impaired in the perception of voicing than place contrasts. This is in contrast to the prediction of Carpenter & Rutherford's study which suggested that place contrasts should be more difficult to discriminate. Thus there is some uncertainty as to which types of acoustic cues (and hence phonetic contrasts) are more difficult for aphasic listeners. Indeed, in a detailed single case study an aphasic listener showed impairments in tests of both temporal processing (gap detection) and spectral processing (formant frequency discrimination, frequency modulation detection, and pitch discrimination) (Morris, Franklin, Ellis, Turner & Bailey 1996). The picture is further complicated by evidence (see below) that, while some aphasic listeners are more impaired in perception of voice contrasts, others show greater difficulty in the processing of place contrasts.

Much of the apparent contradiction in the literature may have arisen from two factors. One is the practice of treating aphasic participants in group studies as being a homogeneous group, without giving detailed information about the precise location of lesions. Since the areas in the auditory cortex responsible for different aspects of both temporal and spectral resolution are anatomically small, minimal variations in the site or extent of lesion are likely to result in different patterns of impairment. A second factor is the notion that acoustic cues can be treated as purely spectral or purely temporal, when they are in fact spectro-temporal. For instance, formant transitions reflect changes in spectral patterns over time, while VOT reflects the timing of aperiodic (consonantal burst and aspiration) and periodic (vocalic) spectral aspects of the signal. Thus discrimination of either of these cues relies on processing of both temporal and spectral information. Nevertheless, some cues are signalled more heavily by spectral information while others are signalled more heavily by temporal information. To this extent the processing of spectral and temporal acoustic cues can be considered dissociable, and either or both may be impaired in aphasia.

There is also suggestive evidence that differences in auditory processing of spectral versus temporal cues in aphasia may be directly related to hemispheric asymmetries in the auditory cortex. It has even been claimed that cerebral dominance for aspects of auditory processing may shift from the left to the right hemisphere during recovery from aphasia. For instance, Moore & Papanicolaou (1988) used a dichotic listening procedure to explore hemispheric dominance for processing of nonsense syllables. They tested groups of chronically aphasic stroke patients, dysarthric stroke patients, non-aphasic right hemisphere stroke patients, and controls. Their results demonstrated a right-ear/left hemisphere advantage for all groups except the aphasic listeners, who showed a trend towards a left-ear/right hemisphere advantage. Similar findings have been reported in two single case studies (Metz-Lutz & Dahl 1984;

Saffran, Marin, & Yeni-Komshian 1976). Saffran et al.'s word deaf patient showed extreme suppression of right-ear signals in dichotic listening. Metz-Lutz & Dahl's patient (also described as having pure word deafness) was shown to have a left-ear advantage for processing verbal material in a dichotic listening task, whilst having at least partial access to semantic representations[3] of spoken words. These symptoms were interpreted as evidence for an increased role of the right hemisphere, and in particular right hemisphere lexical-semantic knowledge, in this patient's auditory processing.

Cerebral dominance for speech perception appears to alter during the first year of recovery from aphasia (Moore, Jr. & Weidner 1975). In a study of dichotic listening in thirty aphasic and ten control participants, it was shown that those aphasic listeners who were less than six months post onset showed no significant ear-advantage. This differed from the control group who showed the expected right-ear advantage. In contrast, aphasic listeners who were more than six months post onset showed a significant left-ear preference, suggesting that in this group the dominance for speech perception processes had shifted to the right hemisphere. Norsell, Ramsing, Rosenhall & Blomstrand (1996) tested one hundred and fourteen patients who had suffered a recent unilateral left hemisphere stroke. Whilst only about 10% of controls showed a left-ear advantage in dichotic speech listening, approximately 25% of the patients showed this pattern. It therefore appears likely that at least some of these patients were experiencing a shift in cerebral dominance very early after stroke.

However, a criticism that can be applied to all of these dichotic listening studies is that they have relied on testing patients at a single point in time, and have inferred the shift in cerebral dominance from comparison with controls. More conclusive evidence of dominance shift might be provided by a prospective longitudinal study, in which aphasic patients underwent repeated dichotic listening tests at regular intervals during the first year after onset. It is also possible that the nature of aphasic acoustic-phonetic encoding difficulties may change over time, with for instance

[3] The terms 'semantic representation' and 'semantic' are used in this thesis to include both lexical-semantic and conceptual knowledge related to word meanings, except where other usage is specified.

discrimination of voicing contrasts improving as the right hemisphere becomes more dominant in processing temporal cues. Longitudinal assessment of phoneme discrimination during aphasia recovery might also test this hypothesis.

An additional complexity to the early stages of auditory processing arises from the existence of an efferent nervous system. Most well known are two sets of descending neural pathways, the medial olivocochlear system and the lateral olivocochlear system. Both of these systems are made up of efferent nerves that descend from the superior olivary complex of the brainstem and innervate the cochlea (Geisler 1998a; Moller 1983). So as well as sending signals to the brain, the cochlea also receives signals from the brain that actually modify its activity. Neurons from the medial olivocochlear system synapse directly with the outer hair cells, and provide them with a form of gain control. Each region of the cochlea receives efferent feedback from that region of the brain stem that it innervates; that is, feedback related to a particular frequency band goes back to almost exactly the same part of the cochlea as generated that information in the first place. The efferent gain control allows the brain stem to selectively dampen or amplify signals within specific frequency ranges; electrical stimulation of efferent neurons in cats has been shown to directly modify the output of the outer hair cells and primary afferent neurons (see Geisler 1998a pp. 256-262 for a review; McCue & Guinan 1994). Further, there are both indirect descending connections from the auditory cortex to the olivocochlear systems, and direct descending connections from both primary and secondary auditory cortex to the cochlear nucleus. This provides mechanisms of both indirect and direct cortical control over the earliest stages of auditory processing. The functions of this auditory feedback system remain poorly understood. One possible function seems to be to improve detection of noise-embedded or degraded signals by selectively amplifying attended frequency regions and damping others.

Limited evidence about the nature of efferent auditory function has been provided by surgical treatment of patients with Meniere's Disease (a vestibular disorder affecting balance). Treatment involves severing the vestibular branch of the auditory nerve, including the olivocochlear pathways. Post-operative perceptual testing of sixteen patients following unilateral treatment has revealed the improved detection of unexpected tones in noise (see Geisler 1998a for a review of studies by Scarf). This effect was shown on a task in which participants heard a long sequence of tones in noise, half of which had the same frequency as an often-repeated cue tone. Detection of other tones is typically poorer in controls, as listeners selectively attend to the frequency of the cue tone. However, following severance of the efferent pathways, listeners showed an improved ability to detect the tones of unexpected compared to expected frequencies. This suggests that the olivocochlear feedback systems normally serve to amplify responses to predicted auditory input and/or suppress responses to unexpected input. The existence of cortical control over peripheral auditory processing has also recently been indicated by several cases in which patients' primary auditory cortex has been surgically removed to control epilepsy (Khalfa et al. 2001). Following surgery, these patients exhibited a reduction of efferent noise suppression in the ear contralateral to the resection. It has also been suggested that the efferent auditory system may play a role in the auditory behavioural inconsistency seen in some patients with auditory agnosia or word deafness. Mendez & Geehan (1988 p.8) suggest that patients who, for instance, show no reaction to sound when engaged in other tasks may be exhibiting the effects of exaggerated suppression of unattended auditory signals. However, the evidence to support this claim remains limited.

It is interesting to consider the consequences that the efferent system may have for speech perception. For instance, it might be possible to shift a frequency response across a categorical boundary between two phonemes that are spectrally similar, if context strongly predicts one phoneme rather than the other. Of course this is conjecture, and for ethical reasons would be very difficult to test since it would involve direct electro-stimulation of nerve fibres. However, a study of speech-in-noise intelligibility by both normal listeners and listeners whose efferent auditory system has been severed showed that noise presented to the contralateral ear improved speech intelligibility in normal listeners but not patients (Giraud, Garnier, Micheyl, Lina, Chays & Chery-Croze 1997). This was interpreted as evidence that the olivocochlear system improves speech perception in noisy environments by reducing the masking effect of the noise. It seems possible that cortical feedback may also have had some influence in improving intelligibility.

There have been separate claims that top-down feedback modulates early auditory processing in aphasia. For instance, it has been suggested that higher level representations in the cortex may influence acoustic-phonetic encoding. One study presented the case of an aphasic individual who showed a selective deficit in the discrimination of voicing contrasts (Caplan & Utman 1994). Interestingly, this deficit was only apparent when the participant was presented with nonwords; discrimination of voicing in word minimal pairs was normal. In addition, lexical decision results showed a pattern of errors on those nonwords that could be made into words by altering the voicing of one segment. The authors suggested an account based on feedback from the auditory input lexicon to the level of acoustic/phonetic processing, whereby sufficient activation of a word at the lexical level could actually alter the encoding of the voicing feature. This feedback could account both for the better discrimination of voicing in words than nonwords, and for the apparent lexicalisation errors in lexical decision. However, the authors do not identify the neurophysiological mechanisms that might be responsible for this feedback. It is unclear whether the efferent system could contribute to such an effect, since it has so far been shown to modulate spectral and amplitude resolution (through frequency specific gain control) rather than temporal resolution.

It has been suggested that the difficulties in discriminating frequency transitions demonstrated by some patients with left hemisphere lesions may indicate an impairment of the processes that adjust the focus of listening to that spectral region that carries the most important information (Divenyi & Robinson 1989). Support for this claim comes from a study comparing detection of tones presented in noise when the frequency of the tone is uncertain, with detection of tones that have a known frequency (Divenyi & Signoret 1980). Some patients required a very much larger increase in the signal-to-noise ratio to detect the uncertain tones than did controls. It could be hypothesised that this effect arises from impaired control of the efferent auditory nervous system, such that cortical activity is unable to effectively modulate cochlear gain. If this is the case then attentional control of speech perception may be impaired, resulting in increased perceptual errors. Errors would be expected particularly under difficult listening conditions, such as in noisy backgrounds or when the auditory input was ambiguous.

The evidence presented so far makes clear that the early auditory processing of speech is highly complex, and is influenced by a range of factors that include both aspects of the acoustic signal, as well as the structure and function of the human auditory processing system. These factors influence the information available to higher levels of auditory processing, which will be considered in the next section.

Phonological Encoding Processes

Most theoretical models of auditory language processing include a stage in which the acoustic-phonetic signal is translated into a phonological representation, typically the phoneme (e.g. Ellis & Young 1988; 1996), or the syllable (e.g. Cutler & Butterfield 1992; Cutler & Norris 1988). However, not all models propose an intermediate abstract phonological representation prior to lexical access. Klatt (1980; 1979) proposed a one-stage perceptual model that made no use of phonemic representations, thus keeping acoustic information available for relatively high-level tasks. (Some support for Klatt's position comes from Marslen-Wilson & Warren (1994) who provided experimental evidence that lexical representations may be directly accessed from featural information in the sound signal, with no intervening level of phoneme classification). Although the nature of the primary phonological representation is debated (e.g. Cutler & Butterfield 1992; Cutler & Norris 1988) it is beyond the scope of this study to test these alternative accounts. We will use the convention of describing phonological representations in terms of phonemes, as have most authors of closely related research. This does not imply that phonemes are necessarily considered more 'real' than other types of representation that have been suggested in the literature; rather, it allows most readily for the findings of this study to be considered against the relevant literature.

The notion of an abstract phonological representation is supported by the phenomenon of categorical perception, which was first demonstrated by Liberman, Harris, Hoffman & Griffith (1957). Acoustic signals are perceived as falling into distinct categories relevant to those phonological contrasts which can signal differences in meaning. This was demonstrated using synthetic syllables varying on an acoustic continuum related to place of articulation. These were perceived distinctly by subjects as /b/ /d/ or /g/ syllables, with narrow acoustic regions marking the boundaries between phonemes. The same effect has been found to occur along the continuum of Voice Onset Time (Liberman, Harris, Eimas, Lisker & Bastian 1961). Nevertheless, categorical perception does not indicate that listeners are insensitive to acoustic variation within categories. It has been shown that, despite categorical perception, listeners can perceive slight acoustic differences between phonemes within the same category (Pisoni & Tash 1974). This suggests that the auditory system is sensitive to changes along the acoustic continuum, but that higher level phonological representations influence perception.

There have been numerous reports of aphasic listeners being impaired in phonological encoding and categorical perception. It is unclear exactly what proportion of people with aphasia experience such difficulties, since phoneme discrimination tends not to be assessed except where an auditory processing deficit has already been identified. Among those studies where groups of aphasic patients have been screened for impairments of phoneme discrimination, the results have varied considerably. For instance, in Varney's study (in which eighty aphasic and ten non-aphasic stroke patients were screened) all of the non-aphasic stroke patients performed normally, while 18% of the aphasic patients made errors on nonword discrimination (Varney 1984). Another study showed that over 70% of aphasic patients had difficulty in phoneme discrimination (Basso, Casati, & Vignolo 1977). Blumstein (1991; 1994) went further and claimed that nearly all people with aphasia show difficulty in discriminating phonological contrasts and/or identifying consonants. To what extent these different results might be due to individual variations between the groups of patients tested is difficult to determine, since these large group studies do not provide detailed individual assessment profiles. Differences might also have arisen from variations between the test stimuli and procedures. Nevertheless, it is clear that a significant proportion of aphasic individuals do have speech perception impairments.

It has also been claimed that speech perception is typically impaired only in patients with damage to or disconnection of Wernicke's area (Buchman, Garron, Trost-

Cardamone, Wichter & Schwartz 1986), and preserved in patients with damage to Broca's area which does not involve the auditory cortex. However, this claim has been undermined by a number of studies that have demonstrated speech perception deficits across aphasia classifications. For instance, in a study of word discrimination in Broca's aphasia, conduction aphasia, and controls, Leeper and colleagues demonstrated that both the aphasic groups were impaired in word discrimination (Leeper, Jr., Shewan, & Booth 1986). Other studies have also shown that phoneme discrimination impairments are not restricted to Wernicke's aphasia (Basso, Casati, & Vignolo 1977; Blumstein, Tartter, Nigro, & Statlender 1984; Tyler 1992b).

Many studies of speech perception in aphasia have analysed discrimination of voice, place and manner contrasts together, rather than distinguishing between different types of single feature contrast (e.g. Howard & Franklin 1988; Maneta, Marshall, & Lindsay 2001; Morris et al. 1996). This approach can identify deficits in discrimination, and has revealed that participants are more likely to make errors when test stimuli differ by only a single distinctive feature (Blumstein 1991). However, testing phoneme discrimination in this way does not necessarily reveal which aspects of phonological encoding are affected. Other studies have tested the discrimination of particular contrasts, most frequently those involving either place of articulation or voicing. It has been suggested that the type of contrasts that aphasic listeners have difficulty discriminating may be related to the anatomical site of lesion. For instance, Blumstein and colleagues (Blumstein, Baker, & Goodglass 1977) compared the phoneme discrimination abilities of aphasic listeners described as Broca's, Wernicke's, mixed anterior, and unclassified posterior groups. They found a correlation between posterior lesions and greater difficulty in discriminating place of articulation. However, this finding is based on a somewhat broad classification of lesion sites. Further research would be required to identify the specific effects of small, localised lesions within the auditory cortex on processing of specific contrasts.

A number of studies have revealed deficits specifically in the perception of voicing contrasts. For instance, results of a group study using a synthesized VOT continuum identified that over 70% of aphasic patients had difficulty identifying the boundary zone between voiced and voiceless consonants (Basso, Casati, & Vignolo 1977). Since this study did not test discrimination of other types of contrast, it is unclear whether the deficit was limited to perception of voicing. Saffran and colleagues described a patient who was assessed as having relatively pure word deafness, six months post-onset of a presumed left middle cerebral artery occlusion (Saffran, Marin, & Yeni-Komshian 1976). Whilst he made errors on both voice and place contrasts, accuracy was lower on voice contrasts. Most convincingly, the patient of Caplan & Utman (1994) described above was tested on both place and voice contrasts, and shown to have a selective deficit that only affected perception of voicing.

Other studies have shown particular difficulties in the perception of place contrasts in aphasia, and have suggested that these may be more common than disorders of voicing contrast (e.g. Baker, Blumstein, & Goodglass 1981; Blumstein, Baker, & Goodglass 1977; Miceli et al. 1978; Tyler 1992b). If these impairments are more common, this may be related to their inherent discriminability since Tyler showed that controls also made more errors on place than voice contrasts in word discrimination (p.72). Blumstein showed that aphasic listeners were impaired in perception of place of articulation on a continuum between /b/ /d/ and /g/ (Blumstein, Tartter, Nigro, & Statlender 1984). Importantly, given claims discussed earlier that aphasic speech perception deficits are due to difficulty processing rapidly changing acoustic information, extending the formant transitions failed to improve discrimination accuracy and in some cases resulted in increased errors.

Another factor that may be important in considering impairments of speech perception is the relative position of a contrast within the word or syllable. Although Tyler reported that contrast position had no effect on word discrimination accuracy for a number of control groups (p.72), Samuel (1990 p.301) discusses an interesting finding from a phoneme restoration experiment. He tested discrimination of words where one segment had added noise, and of words where one segment was deleted and replaced with noise. Participants were asked to judge whether the word was complete. He compared performance between items when the test word was presented in isolation and items when the test word was presented immediately after cueing with a complete and unaltered token of the same word. He found that listeners were more likely to restore the missing phoneme in the cued condition, and that this effect increased for later occurring segments. Further evidence, which will be discussed below in relation to spoken word recognition, indicates crucial differences between the processing of early and late occurring phonemes in normal listeners. These differences are important for understanding how the output of phonological encoding maps onto entries in the auditory input lexicon. The effect of contrast position will also be shown in chapter five to be important for understanding how lexical representations may interact with phonological encoding.

Few studies have reported the effect of the position of a contrast within the syllable/word on aphasic phoneme discrimination. One exception to this is Howard & Franklin (1988) who tested discrimination separately for initial and final contrasts. Their patient (MK) scored 91% correct for initial contrasts and 97% correct for final contrasts in nonwords. Without any normative data for comparison, the authors concluded that his phoneme discrimination was adequate for word comprehension and presented no analysis of the influence of contrast position. However, normative data on a similar task used in the study presented here (see chapter five) suggests that MK's discrimination of initial contrasts may have been impaired. The reason for his better performance on final contrasts is difficult to determine since the authors do not present the actual stimuli used nor indicate the types of contrast tested. For instance, if many of the items tested perception of voicing contrasts in plosives, it might be predicted that a patient would be more accurate discriminating contrasts in final position. This is because the temporal cues to final voicing carried by the preceding vowel duration (at least in English) are acoustically much more salient than the differences in VOT that mark voicing in initial plosives. In contrast to MK, Tyler (1992b) reports one aphasic patient (JG) who makes more errors on word final contrasts, particularly those involving place of articulation (p.74). Interestingly, JG was also insensitive to word-final phonemic distortions of words in sentences, such that the distortion resulted in a nonword.

A more detailed analysis of the role of contrast position was carried out by Utman et al, who explored the effects of acoustic distortions of prime words on auditory lexical decision (Utman, Blumstein, & Sullivan 2001). They compared speed of response to words preceded by intact primes (e.g. 'cat'-'dog'), primes distorted by a single feature to produce a poorer exemplar (e.g. 'c*at'-'dog'), and unrelated words (e.g. 'ring'-'dog'). Within the distorted prime condition, they compared the effects of distortions of the initial contrast with distortions of the final contrast. They found that the control group showed a small and transient reduction in the priming effect for primes distorted in either initial or final position. However, participants with Broca's aphasia showed a marked reduction in priming following word-initial distortions, but only a weak reduction in the priming effect following word-final distortions. In both positions, the effect of the acoustic distortion on priming was greater for those primes that had a close lexical competitor than for primes that had no lexical competitor. The authors argued that this was evidence of reduced lexical activation in Broca's aphasia. Distortions of word-initial segments seriously disrupted the activation of lexical candidates from auditory input, thus limiting the potential for distorted primes to speed processing of the subsequent word. However, when word-final segments were distorted this had only a limited effect on priming since the intact word-onset had already activated the lexical candidate.

Gardner and colleagues also considered the effect of contrast position in their study of the effects of speech rate and semantic redundancy on spoken word comprehension by aphasic listeners (Gardner, Albert, & Weintraub 1975). They noted that those aphasic listeners that were prone to making phonemic errors in comprehension tended to confuse words that began with the same sound rather than words that ended with the same sound. This is in keeping with the notion (discussed below in relation to word recognition) that word onsets activate a cohort of possible candidates, with confusions mainly occurring among these competitors. Word endings play a much lesser role in activation of the cohort, being used rather to determine selection of the winning candidate. Thus a word was unlikely to be confused with another word that did not share its onset, since that word would not have entered the initial cohort.

An important factor that has been shown to influence categorical perception in normal listeners is word-context (Ganong 1980). Ganong varied an ambiguous phoneme along an acoustic continuum from /k/ to /g/, and inserted this in front of a word-ending such as *'__iss'*. The word context was found to influence the perceptual changeover point; subjects were willing to put a sound into a category they would not otherwise do if the result produced a real word. So a phoneme close to the midpoint, that in isolation would be categorised as /g/ (thus producing the nonword *'giss'*) would be perceived as /k/ (thus producing the word *'kiss'*). When the same ambiguous phonemes were presented with the word ending *'_eese'*, listeners were more likely to categorise them as /g/ (thus producing the word 'geese') than as /k/ (which would produce a nonword). In discussing a similar experiment, Connine & Clifton confirmed that lexical knowledge is invoked to disambiguate when the acoustic signal is close to the boundary between voiced and voiceless plosives. However, they argued that it is not used further along the acoustic continuum where perceptual information alone is sufficient to make a decision (Connine & Clifton 1987).

It has also been shown that lexicality influences perception of unambiguous phonemes by normal listeners under certain conditions. The Verbal Transformation Effect (VTE) is an effect that occurs when listeners hear a series of rapid repetitions of the same spoken input (Warren 1968). Listeners typically perceive illusory changes or transformations in the input, indicating that their perceptions are based not only on information contained in the acoustic signal. For instance, rapid repetition of the word *'plane'* might be perceived by listeners as a changing series including the words *'plane'*, *'play'* and *'flame'*. It has been demonstrated that the number of unique transformations reported during a presentation of a repeated stimulus is affected by lexical status (Natsoulas 1965; Pitt & Shoaf 2001). When the stimulus is a nonword, listeners report more transformations, and fewer instances of the actual input, than when the stimulus is a word. This suggests that lexical representations play a role in stabilising auditory processing by providing what has been described as a 'perceptual anchor'.

Given the difficulties outlined above that some aphasic listeners have with early acoustic-phonetic processing, it might be predicted that lexical knowledge would play a greater role in perception by aphasic than normal listeners. The aphasic patient described by Caplan & Utman (1994) provides clear evidence that some aphasic listeners are able to discriminate phonemes in words but not in nonwords. Boyczuk & Baum (1999) also presented evidence from a group study showing that fluent aphasic, nonfluent aphasic, and non-aphasic elderly participants all showed effects of lexical status on the shift in category boundary for ambiguous phonemes on a VOT continuum. Such cases are important in evaluating those models of auditory processing based on unidirectional flow of information from the acoustic signal to the lexicon, and will be considered in chapter seven. However, it is certainly not the case that all aphasic listeners show differences in the discrimination of words and nonwords. For instance, the individual (JS) described by Morris et al. (1996) performed at chance levels on both word and nonword minimal pairs. It is possible that effects of lexicality on discrimination are revealed only when discrimination itself is less severely impaired, with JS's equally poor performance on both words and nonwords being associated with his severe discrimination deficit. (However, it will be seen in chapter five that effects of lexicality on phoneme discrimination do not necessarily correlate with severity of the deficit in the participants tested in the current study).

The insights described earlier into the effect of contrast position on discrimination could be usefully exploited to provide information about the locus of lexical effects on speech perception. If phoneme discrimination were compared not only between nonwords and words, but also between early and late occurring contrasts, then it should be possible to identify whether lexical representations affect phonological encoding or only post-perceptual selection processes. If lexical representations do affect initial encoding, then we could predict differences between words and nonwords in the discrimination of initial contrasts. However, if the effect of lexical representations is restricted to post-perceptual decision-making processes, then any word-nonword differences in discrimination should be largely limited to later occurring contrasts. An experiment that tests these predictions on the processing of normal and aphasic listeners will be presented in chapter five.

There is considerable evidence to suggest that not only lexical representations, but also semantic and sentence contexts, may influence speech perception. For instance, Miller and colleagues showed that normal listeners were able to identify words in a noisy background more easily when they were presented in a sentence than when the same words were presented in isolation (Miller, Heise, & Lichten 1951). They also found that the greater the number of words in the predetermined set which subjects were listening for, the more intense the signal had to be relative to the noise for the subjects to identify them. Bruce (1958) similarly showed that words against background noise are recognised more accurately when in a meaningful context. More recently, it has been claimed that adults with high frequency hearing loss are more susceptible than those with normal hearing to the masking effects of background noise on speech recognition (e.g. Frisina & Frisina 1997), but that both young and older adults with normal hearing benefit equally from meaningful sentence contexts in recognising words against noisy backgrounds (Dubno, Ahlstrom, & Horwitz 2000).

Some interesting evidence about the effect of context on the generation of phonological representations comes from the work of Miller & Niceley (1955), who showed that normal listeners can fill in missing acoustic information provided that words are spoken within a clear semantic context. Listeners' perceptions of words in sentences were tested after acoustic information about place of articulation of some target consonants had been changed. In one example, the first phoneme of *'bottle'* was altered to produce [γΘτλ]. The recordings were then distorted to impoverish the acoustic information available. Listeners perceived these distorted words to be the correctly articulated targets. This phenomenon is closely related to the Phoneme Restoration Effect described by Warren and colleagues. Warren (1970) and Obusek & Warren (1973) presented subjects with sentences in which one phoneme was replaced with a cough e.g.

> '*The state governors met with their respective legi*latures convening in the capital city.*'

Subjects could not detect that a sound was missing from the sample. Even when they were told that a phoneme was missing they still reported that they could hear it, and were unable to correctly locate the cough in the speech. The same restoration effect occurred when larger portions of the word were deleted e.g. '*le***latures*'. It was argued that the processing of individual phonemes in this task was influenced by semantic and syntactic information.

Warren & Sherman (1974) showed that listeners would perceive a distorted word differently depending on the linguistic context. Participants were presented with a sentence containing one word where a phoneme was replaced with a cough. Different words were then spliced onto the end of the sentence. For example:

1) *'It was found that the *eel was on the orange.'*
2) *'It was found that the *eel was on the axle.'*
3) *'It was found that the *eel was on the fishing-rod.'*
4) *'It was found that the *eel was on the table.'*

The result was that listeners restored a phoneme that would make an appropriate word for the sentence context. So in the example sentences given, participants reported hearing 1) *'peel'* 2) *'wheel'* 3) *'reel'* 4) *'meal'*. Replacing deleted phonemes with silence was easily detected and did not produce the effect, indicating that some acoustic input is required for a missing phoneme to be restored.

These studies have been interpreted as suggesting that subjects are using lexical hypotheses to aid in auditory-phonemic analysis. It is unclear however, whether phoneme restoration is truly operating at a pre-lexical level since the tasks used by Warren and colleagues are carried out off-line. Fodor questioned the interpretation that semantic/syntactic information constrains speech perception, suggesting instead that the restoration may occur at a higher-level even than phonological processing (Fodor 1983). It is certainly arguable that the restorations demonstrated in this task must take place at higher levels of representation, since the semantic context is not provided until after initial phonological encoding has taken place. However, Samuel compared the effects of replacing a segment with noise (as carried out by Warren et al.) with the effect of adding noise to the segment (Samuel 1990). The intention of this was to separate out true perceptual from post-perceptual restoration effects. If phoneme restoration were truly perceptual, listeners should perceive the segments in both conditions as intact phonemes with noise added. Using a signal detection paradigm, he found that listeners could distinguish between the two conditions when segments were presented in isolation. However, when the segments were presented as part of a word, listeners could not tell the noise-replaced from the noise-added phonemes. This suggested that the lexical context was indeed contributing to the perception of the deleted phoneme as being intact.

The effects of semantic and sentence contexts have also been claimed to influence speech perception by aphasic listeners. For instance, Saffran et al (1976) presented evidence of the role of higher level representations in the perception of phonemic contrasts in their case study of a word deaf patient. They had observed, based on anecdotal evidence, that "like normals under noisy conditions, the word-deaf patient can use contextual information to compensate, in part, for his phonemic deficit" (p.223). Videotaped conversations showed that the patient appeared to follow conversation when restricted to one topic, but often got lost when topics changed[5].

One of the areas that Saffran and colleagues investigated was the effect of context on auditory word processing. In one experiment they examined the effect of semantic category cues on word repetition. They found that single word repetition significantly improved when stimuli were grouped into semantic categories than when they were presented in random order. This beneficial effect increased for items presented later in a category grouping. They suggested that word recognition may have been enhanced by the predictive context provided by the category grouping. One obvious criticism of this conclusion is that the data do not distinguish between semantic facilitation operating on input or output processes, since both are involved in repetition.

Another experiment with the same patient examined the effect of embedding words in sentences on word recognition. They presented twenty-five spoken stimulus words both in isolation, and in sentences. The patient was asked to underline the target word from a written list of three, where the distractors were rhyming minimal pairs. In one example, the spoken sentence was '*The boy sailed a boat*', and the choice of written words was '*boat, goat, coat*'. The results showed a significantly improved recognition performance when the words were embedded in predictive sentences. This is in keeping with the findings of Miller, Heise & Lichten (1951), and of Bruce

[5] Similar anecdotal evidence from earlier cases of word deafness (Hemphill & Stengel 1940; Klein & Harper 1956) is cited by Saffran et al (1976).

(1958) that normal listeners are assisted in recognition by a clear semantic context. Saffran et al concluded that embedding words in a sentence or semantic category context considerably improved intelligibility, despite their patient's poor performance on sentence comprehension. They suggested that auditory analysis is so deficient in word deafness that the patient is unable even to guess what he has heard, but that processing other information supplied along with the speech signal can apparently compensate for deficits at the phonetic level (p.225). Of course, some auditory analysis must still be possible in order for the contextual linguistic representations to be generated.

In the study mentioned earlier, Gardner, Albert & Weintraub (1975) explored the influence of semantic redundancy on spoken word comprehension in aphasia. They constructed a set of tests in which participants were asked to select a picture corresponding to a spoken word from an array that included phonological foils. Target words were presented under a range of conditions, including target spoken in isolation, target embedded in a neutral (low redundancy) sentence, target embedded in a semantically supportive (high redundancy) sentence, and target embedded in a semantically deceptive sentence. They found that patients made more errors on words presented in a semantically deceptive sentence, and fewer errors when words were presented with high than low redundancy. This indicates that some aphasic listeners may rely heavily on the semantic context to support their processing of heard words, even when the context is incongruent with the auditory input. However, one limitation of this study is the reliance on sentence contexts to test for effects of semantic redundancy. Since difficulty in comprehending sentences is a very common feature of aphasia, it is difficult to be certain that participants will always generate the intended semantic context from the sentence stimuli. This introduces an uncontrolled variable into the experiment, and one that could have a profound influence on the question of whether semantic redundancy influences perception. Pictures constitute a type of context that might provide a more reliable test of the effects of semantic redundancy on aphasic perception; a phoneme discrimination experiment that uses picture contexts will be presented in this study (see chapter six).

It has also been demonstrated that non-linguistic context can influence speech perception in aphasia. Records (1994) explored the interaction between phonemic ambiguity and referential gestures in aphasia. Participants heard synthesised speech stimuli along a voicing continuum between the words '*coat*' and '*goat*', and were asked to point to which of two corresponding pictures matched the word they had heard. This task was presented in one condition without any additional cues, and in a second condition with referential cues provided by a video recording of a person pointing at the pictures. On some trials the referential gesture indicated the correct picture, on some trials it indicated the incorrect picture, and on other trials was ambiguous. The purpose of this task was to assess the degree to which participants relied on the auditory input, and the degree to which they relied on the gesture in making their choice between the pictures. Results showed that those participants who were more severely impaired in auditory comprehension showed the greatest effect of gestural cues. Further, it was demonstrated that the influence of gesture was greater for those items that were acoustically ambiguous between the two word end-points of the continuum. These findings indicate that aphasic listeners make greater use of contextual information to guide speech perception, particularly when acoustic information is unclear. This is related to Connine & Clifton's (1987) finding (reported earlier) that normal listeners tend only to make use of lexical information to disambiguate acoustically ambiguous phonemes. Due to the greater uncertainty in acoustic-phonetic encoding experienced by aphasic listeners, this effect appears to be greater than that found in controls.

However, the tasks employed by Saffran et al., by Gardner et al., and by Records, were all off-line in nature. It is therefore uncertain whether the effects of context that they demonstrated in these aphasic listeners actually influenced phonological encoding, or post-perceptual decision making processes. Further evidence is required to determine how far higher level representations might influence pre-lexical speech perception. This issue will be considered in relation to two experiments that explore the influence of lexical and semantic contexts on phonological encoding by control and aphasic listeners (see chapters five and six).

Spoken Word Recognition Processes

The processes involved in mapping from abstract phonological representations onto words in the lexicon are complex. The most influential account of these processes has been the Cohort Model (Marslen-Wilson 1990; Marslen-Wilson & Welsh 1978). According to this theory, listeners activate a cohort of all the words in the lexicon that match the auditory input when they hear speech. At the onset of the word the cohort may consist of many candidates, since many different words may share the same initial segment. For instance /kæ/ could be the beginning of *'cat' 'cap' 'captain' 'cash'* and so on, so all of these words will initially be activated within the cohort. As more of the word is heard over time, some of these candidates will be eliminated from the cohort since they no longer match the input. So in this example, if the next segment to be heard were /p/ then the words *'cat'* and *'cash'* would no longer be compatible, leaving only *'cap'* and *'captain'* activated. This process would continue as more of the word unfolded until only one candidate remained active, and at this point the word would be recognised. This point has been called the 'uniqueness point', and is the point at which the word can be differentiated from all other words in the language. Whilst in monosyllabic CVC words this point will usually coincide with the final consonant, in longer words it may occur considerably earlier than the end of the word. For instance, the word *'cathedral'* becomes unique at the second-syllable vowel, since no other word in English commences with /κ□∀Tι/. An important consequence of this is that listeners do not necessarily need to hear the whole word in order to recognise it. In fact, it has been demonstrated that listeners can recognise words (the 'recognition point') even before the uniqueness point has been reached provided there is a clear context that favours one candidate over all others.

Predictive contexts have often been generated through the use of semantic primes. It has been argued that semantic priming effects arise because the prime generates an 'expectancy set' for related target words (Becker 1980). Where the relationship between the prime and target produces a small expectancy set, for instance when the stimuli are pairs of antonyms, the facilitatory effect on reaction times is large. However, when the relationship between prime and target produces a large expectancy set, for instance when stimuli consist of superordinate-subordinate pairs, then the facilitatory effect on reaction times is small. This view has also been applied to sentence contexts by Schwanenflugel & Shoben (1985), who explored the facilitating effects of sentence primes on word recognition. They found that the higher the level of sentence constraint, the greater the facilitatory effect of that sentence on word recognition. They claimed that highly constraining sentence contexts both increase expectations for congruent words and decrease expectations for incongruent words.

The exact role of context in influencing recognition has been the source of considerable debate. In the earliest version of the Cohort Model, context was allowed to eliminate implausible candidates from the cohort at an early stage. However, Marslen-Wilson later revised this premise in line with experimental findings, restricting contextual influences to selection of the winning candidate once the uniqueness point had been reached (Marslen-Wilson 1990)[6]. This was in response to evidence from the gating task that sentence contexts did not initially prevent activation of words that were unlikely to make sense (Grosjean 1980). In any case, an important implication of the Cohort Model is that the phonological encoding of initial contrasts is much more important to lexical access[7] than encoding of final contrasts.

The ability of aphasic listeners to recognise spoken words cannot however be easily predicted on the basis of their phonological encoding. It has been suggested that

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[6] In the original Cohort Model lexical activation was not affected by word frequency. All words that were consistent with the incoming signal entered the cohort, and all were equally active. In the revised Cohort Model (Marslen-Wilson 1987) word frequency influenced activation of word candidates. Words could be activated to any point on a scale from fully off to fully on, and words of higher frequency started with higher levels of resting activation. High frequency words also had a faster rate of gain in activation than low frequency words and so would be recognised faster.

[7] The term 'lexical access' is used to refer to the activation of phonological word-forms, although it is recognised that in normal listeners this typically involves automatic activation of semantic representations as well. Where discussion specifically includes both phonological and semantic representations of words, the term 'lexical-semantic' will be used.

lexical processing may occur despite profound impairment of phoneme discrimination, in a pattern sometimes described as Deep Dysphasia (Duhamel & Poncet 1986). These authors describe a patient with a profound discrimination impairment resulting from damage to the left temporal lobe auditory areas, who they claim could nonetheless recognise spoken words. They suggested that he may have been relying on the right hemisphere to carry out normally left-dominant operations, but without access to the level of phonological analysis available in the left temporal lobe. However, their claim that he could recognise words was based on the fact that in auditory lexical decision he scored 29/30 for words and 16/30 for nonwords. An alternative interpretation of this result is that his lexical access was in fact impaired but that he displayed a strong positive response bias. More reliable findings have been reported in cases of word form deafness, in which listeners are unable to recognise words despite adequate phoneme discrimination (e.g. Berndt & Mitchum 1990; Franklin 1989; Howard & Franklin 1988; Martin, Breedin, & Damian 1999). In some cases it has been claimed that the deficit in recognising words arises from an impairment of auditory short-term memory. For instance, Martin et al. described a patient (AP) who performed normally on phoneme discrimination, and yet had a strong tendency to identify nonwords as words on auditory lexical decision. These authors claimed that their patient's performance in phoneme discrimination, lexical decision and repetition could all be accounted for in terms of rapid decay of activation at the phoneme level; that is, that the representation of an earlier phoneme decays while later phonemes are processed. They tested this hypothesis using a computational model of interactive activation with feedback from the lexical to the phoneme level. This model produced results compatible with AP's performance when decay rate at the phoneme level was speeded up, but not when word-decay or several other parameters were altered. On the basis of this, the authors predicted that AP's speech discrimination would deteriorate if task demands introduced a longer delay between hearing the input and responding. They compared discrimination of nonwords with inter-stimulus intervals (ISI) of 500 and 2000 milliseconds. Whilst performance of a control group only dropped from a mean 97% correct at the shorter ISI to 95% at the longer ISI, AP's performance dropped from 96% to 84% respectively. This confirmed that he was able to encode phonemes accurately, but was unable to maintain accurate phonological representations over time. Another case in which an aphasic listener (described as pure word deaf) had difficulty processing a second syllable while retaining the representation of the first was reported by Nakakoshi, Kashino, Mizobuchi, Fukada & Katori (2001). The suggestion that some auditory processing difficulties in aphasia may result from rapid decay of representations, as has been claimed for other aphasic deficits (such as agrammatism, see Kolk (1995)), will be considered further in relation to experimental findings in chapter five.

A number of psycholinguistic variables have been shown to influence the ease with which spoken words are recognised in both normal and aphasic listeners. Among the most important of these are neighbourhood density, and word frequency. Neighbourhood density refers to the number of words that share a similar phonological form. Normal listeners recognise words more quickly if they have few phonological neighbours (Luce, Pisoni, & Goldinger 1990). This has been taken as evidence of competition between lexical candidates within the cohort. When a word onset is compatible with many lexical forms, they are all activated to some degree thus slowing down the recognition process. However, when few words share the same onset (as in /zIg/ which is only compatible with 'zigzag'), there is little competition and recognition is faster. While Luce and colleagues have demonstrated neighbourhood density effects for words that share either a common onset or a common ending, Marslen-Wilson has argued that strong effects are only found in words with the same onset (Marslen-Wilson & Zwitserlood 1989). These authors maintain that the activation of words in the lexicon unfolds sequentially over time, with word onsets being crucial in determining which candidates enter the initial cohort.

Effects of neighbourhood density have also been demonstrated in aphasic listeners, with faster responses to words with few neighbours in auditory lexical decision (Tyler, Voice, & Moss 1996). In the Utman et al (2001) study of the effects of acoustic distortion of the prime word on semantic priming (described earlier), a further factor that was explored was the interaction between the acoustic distortion and the presence/absence of a lexical competitor. Some of the distorted primes resulted in items that were ambiguous between the intact prime and a phonological neighbour (e.g. reduction of VOT in the initial segment of '*coat*' produced a prime somewhere between '*coat*' and '*goat*'). Other distortions did not result in lexical ambiguity since there was no close phonological neighbour (e.g. reduction of VOT in the initial segment of '*cat*' produced a prime somewhere between '*cat*' and the nonword '*gat*'). For distortions in both initial and final positions, the reduction in priming effect demonstrated by Broca's aphasics was greatest for those primes that were lexically ambiguous. This seems to indicate that these aphasic listeners were particularly vulnerable to lexical competition for acoustically degraded input.

Normal listeners respond faster to words of high than low frequency in a number of auditory processing tasks (Bradley & Forster 1987; Goldiamond & Hawkins 1958; Grosjean 1980; Morton 1979; Tyler 1984; Whaley 1978), and they are more accurate in recognising high than low frequency words against background noise (Broadbent 1967). Such effects have often been interpreted as showing that repeated exposure to a word reduces that word's activation threshold (Morton 1979). Less incoming activation is therefore required for a high than a low frequency word to be accessed. Word frequency effects have been demonstrated in some studies of auditory lexical decision in normal listeners (e.g. Marslen-Wilson 1990), but not in others (e.g. Martin, Breedin, & Damian 1999). Bradley & Forster (1987) have suggested it can be harder to demonstrate frequency effects on reaction times in spoken than written word recognition, because these effects are detectable over a much briefer time span for auditory input. Other authors have suggested that word frequency effects are short lived, and that they are restricted to early lexical access rather than decision stage processing (Dahan, Magnuson, & Tanenhaus 2001). It has also been demonstrated that word frequency interacts with neighbourhood density. For instance, words that have high frequency neighbours are recognised more slowly than words with low frequency neighbours (Luce, Pisoni, & Goldinger 1990; Marslen-Wilson 1990).

The effects of word frequency on spoken word recognition have not been demonstrated consistently in aphasic listeners. For instance, Martin et al's (1999) patient showed no effect of frequency on auditory lexical decision. In their description of a patient with abstract word meaning deafness, Franklin and colleagues also pointed out that performance in tasks including word repetition and auditory word association was unaffected by word frequency (Franklin, Howard, & Patterson 1994). This is perhaps unsurprising given that effects of frequency are manifested in fleeting changes to online processing speed in normal listeners (for whom significant effects are not always shown). Analysis of response accuracy alone may not reveal subtle effects of frequency, and aphasic response speeds tend to be slower and more variable than those of controls (see chapter four). Tyler (1992a) also makes a distinction between online tasks that tap intermediate stages of representation during processes of lexical access, and offline tasks that tap only final output representations. The auditory lexical decision task usually falls into the latter category (unless it is speeded), and is therefore less likely to reveal fleeting effects of frequency on intermediate stages of processing. Lack of frequency effects in aphasic auditory processing might also in part be explained by differences in how the left and right hemispheres respond to word frequency. Researchers have used a divided visual field task in which written sentences containing a lexically ambiguous item were presented to either the right or left visual field of normal subjects (Coney & Evans 2000). The ambiguous word had at least one common and one uncommon meaning. The effects of the lexically ambiguous item were measured on lexical decision reaction times to words that were semantically related to one of the ambiguous word's meanings. Results showed that processing of the ambiguity by the right visual field/left hemisphere lead to the more frequent meanings being activated first. However, when presented to the left visual field/right hemisphere, multiple meanings were activated simultaneously without any effect of word frequency. If it is the case that the right hemisphere is insensitive to word frequency, then it might be hypothesised that aphasic listeners who rely on right hemisphere processing to a greater degree than normal listeners would show less influence of frequency.

The suggestion that we actively form lexical hypotheses when listening to speech, which was discussed earlier in relation to phonological encoding, is supported by the work of Grosjean (1980). The gating paradigm involves measuring reaction times in a word recognition task using word fragments of varying lengths. It has been shown that normal listeners are able to recognise spoken words from very small fragments (Marslen-Wilson & Welsh 1978), with a preceding semantic context enabling listeners to recognise a word even before the first phoneme is complete (Tyler 1984). A number of studies have shown that preceding semantic context also influences auditory word recognition in aphasic listeners. For instance, Blumstein, Milberg &

Shrier showed that a group of Wernicke's aphasics had faster reaction times to real words in a lexical decision task when the stimuli were preceded by semantically associated words (Blumstein, Milberg, & Shrier 1982). This is despite the fact that the subjects were unable to make judgements about semantic relatedness, and also made semantic errors in auditory word to picture matching. This suggests that semantic information can mediate auditory word recognition even in patients that have semantic deficits.

Milberg, Blumstein & Dworetzky (1988) used a primed lexical decision task to explore interactions between phonological encoding and lexical processing in aphasia. They compared the priming effect of intact words with words that were distorted in one phoneme so as to produce a nonword. Within the set of distorted primes, they compared the effects of words distorted by one phonetic feature with words distorted by two features. So in one example, they compared the priming effect on the word '*dog*' of the primes '*cat*', '*gat*' and '*wat*'. They found that the responses of normal listeners in lexical decision were strongly primed by the intact word, weakly primed by the single-feature distortion, and not primed by the two-feature distortion. Aphasic listeners, however, showed different effects. Broca's aphasics showed priming only from the intact word, whereas Wernicke's aphasics showed priming in all three conditions. These results were interpreted as showing that Broca's aphasics have raised thresholds for lexical activation, and require the strong input activation from an intact word in order to trigger lexical access. The Wernicke's aphasics have lowered thresholds for lexical activation and trigger lexical access from poorly matching acoustic input, resulting in excessive competition between lexical candidates.

This claim has been tested in a connectionist simulation of lexical access (McNellis & Blumstein 2001). This model was able to replicate a number of earlier findings by Blumstein and colleagues regarding the effects of priming and acoustic distortion on lexical activation in aphasic listeners. By adjusting resting activation levels and the strength of feedback between lexical and phoneme representations, the model produced behaviour that imitated patterns of lexical activation in Broca's and Wernicke's aphasics. However, Blumstein's claim that Broca's aphasics show a selective impairment in the automatic activation of word forms and meanings has been challenged. Katz used an auditory lexical decision task to test automatic semantic priming in non-fluent aphasic listeners and controls (Katz 1988). It was found that both groups showed faster decisions for words that followed semantically related primes, than for those following unrelated words. Ostrin & Tyler (1993) have also challenged Blumstein's account. They reported the auditory lexical decision performance of four participants with Broca's aphasia, all of whom showed effects of semantic priming on speed of response. The authors of both these studies argue that this priming effect indicates normal patterns of lexical-semantic activation, and is inconsistent with these aphasic listeners having raised thresholds for lexical access.

Importantly, it has been demonstrated that word recognition is not only influenced by a preceding semantic context, but also by semantic attributes of the word itself. In their study of MK, Howard & Franklin (1988) showed that he clearly uses semantic information to mediate auditory word recognition. MK showed an imageability effect in auditory lexical decision, making more errors on low imageability words (for which his access to semantics was poor) than high imageability words (for which he could retrieve relatively good semantics). Since imageability is a semantic property, MK must have been accessing semantic information in the process of word recognition. Imageability has also been demonstrated to influence word recognition in normal listeners, whose responses are faster to high imageability words (De Groot 1989; Tyler, Voice, & Moss 1996), and to interact with word frequency (James 1975) in lexical decision. These findings are important to the evaluation of models of auditory processing in which the flow of information between the lexicon and the semantic system is unidirectional. An experiment will be presented in chapter four that investigates the effects of word frequency and imageability on auditory lexical decision by normal and aphasic listeners. This experiment will also explore interactions between these factors and a predictive semantic context on the speed and accuracy of spoken word recognition.

A further point that should be taken into account in considering spoken word recognition processes is the role of attentional factors. Hugdahl, Thomsen, Ersland, Rimol & Niemi (2003) used an event related fMRI study to investigate the effects of attention during speech perception on neuroanatomical activation. Participants heard a set of speech stimuli including a combination of single vowels, pseudowords and words. There were four conditions of listening instructions. Participants were asked to 1) listen passively 2) attend to the vowels 3) attend to the pseudowords, or 4) attend to the words. Each of these conditions produced activation in different neuronal areas. For instance both passive listening and pseudoword conditions produced symmetrical bi-hemispheric activation, whereas both the vowel and word conditions produced leftward asymmetry. The authors concluded that "attention plays a modulatory role in neuronal activation to speech sounds, producing specific activations to specific stimulus categories that may act to facilitate speech perception.". The role of attention to different levels of representation will be considered further in relation to the effects of picture contexts on phoneme discrimination (see chapter six).

Spoken Word Comprehension Processes

Considerable research into the processes involved in normal and aphasic comprehension of spoken words has been reported, and it is beyond the scope of this thesis comprehensively to review this literature[8]. Instead, this section will focus on some key findings that are important to the consideration of contextual influences on phonological encoding and spoken word recognition, particularly in aphasia. These are grouped into three categories: i) dissociations between speech discrimination, word recognition and comprehension in aphasia, ii) effects of the semantic attributes of words, and in particular of imageability, on comprehension, and iii) effects of semantic contexts on spoken word comprehension.

[8] Useful reviews of a wider range of factors influencing word comprehension are provided by (Marslen-Wilson 1989; Moss & Gaskell 1999; Schreuder & Flores d'Arcais 1989; Tyler 1989).

Dissociations between discrimination, recognition and comprehension

If higher level representations played no role in the auditory processing of speech, then a severe deficit in phoneme discrimination or in the recognition of word-forms should always result in a severe auditory comprehension deficit. However, evidence was discussed earlier that impairments of speech perception and word recognition are partially dissociable. Dissociations have also been demonstrated in aphasic listeners between speech perception and comprehension, and between word recognition and comprehension. Blumstein (1991) observed that some patients with impairments in phoneme discrimination have good auditory comprehension, while other patients with severe auditory language comprehension deficits have little or no difficulty in phoneme discrimination (p 169). For instance, a study including sixteen aphasic participants demonstrated that difficulties in discriminating voice onset time and in labelling voiced and voiceless consonants did not always correlate with performance in auditory comprehension (Blumstein et al. 1977). Another study showed that those patients who had greatest difficulty with phoneme discrimination were only moderately impaired in auditory comprehension (Blumstein, Baker, & Goodglass 1977). Conversely, in that study a group with Wernicke's aphasia whose auditory comprehension was more severely impaired than other groups showed only moderate deficits in phoneme discrimination. Varney also demonstrated that some aphasic listeners with severely impaired phoneme discrimination are only moderately impaired in auditory comprehension on a spoken word-to-picture matching task (Varney 1980). Other studies have also failed to show any systematic or strong correlation between phoneme discrimination and comprehension in aphasia (Basso, Casati, & Vignolo 1977; Blumstein, Baker, & Goodglass 1977; Jauhiainen & Nuutila 1977; Miceli, Blumstein & Dworetsky 1980).

Blumstein (1991 p.169) suggested several hypotheses to explain the dissociation between discrimination and comprehension found in such studies. These included the possibilities that: i) speech perception deficits may only be revealed in the context of larger streams of speech than those tested, ii) that the extraction of meaning from the auditory signal may rely on acoustic patterns other than the segmental cues typically assessed in phoneme discrimination, and iii) that the underlying deficit in auditory comprehension reflects an inability to relate phonological representations to meanings. It may be that some of the differences can be accounted for by differences in the task demands between discrimination and comprehension tasks, with some types of comprehension task (such as word-picture matching) being relatively easy. A further possibility that will be considered in this thesis is that some aphasic listeners may be able to compensate for impaired speech discrimination in comprehension tasks by greater reliance on relatively intact top-down processing. Some support for this suggestion will be reported below.

In addition to the dissociation between perception and comprehension, it has been shown that auditory comprehension may be impaired in spite of intact abilities to recognise spoken words. This pattern, which in its pure form is known as word meaning deafness and includes intact written comprehension, is rare. For instance Franklin (1989) presented the case of DRB, who was unimpaired in both auditory lexical decision and written synonym matching tasks, but severely impaired in auditory synonym matching. In another case, a patient (DrO) presented with impaired auditory comprehension affected by both imageability and word length, yet intact written comprehension (Franklin et al. 1996). DrO performed well on auditory lexical decision and was able to repeat words that he could not understand. This suggested that he was able to access intact representations of word-forms, but had an impairment of mapping processes between word-forms and meanings. Less 'pure' forms of the disorder have been described in a number of cases (see Franklin, Howard, & Patterson 1994 for a review). An implication of cases where access from spoken word-forms to meanings is impaired is that some aphasic listeners may be limited in the degree to which they can use linguistic-semantic context to support their auditory processing of speech; if access to semantics from heard words is so impaired that word meanings are often absent or poorly defined, then there may be little opportunity for semantics to support earlier stages of speech processing. Some evidence[9] to support this hypothesis will be presented in chapters three to six.

[9] (This evidence relates to JW, a participant in the current study who shows little effect of lexicality yet a strong effect of picture contexts on phoneme discrimination).

Semantic attributes of words

Comprehension of spoken words is influenced by a number of factors, and these must be taken into account when considering interactions between comprehension and discrimination. Some of these factors arise from aspects of a spoken word's semantic representation, such as concreteness and imageability. Typically, words that are concrete or highly imageable are easier to understand than words that are abstract or have low imageability. For instance, normal listeners respond faster to high imageability words in word association tasks (De Groot 1989), while Franklin (1989) demonstrated that a number of individuals with fluent aphasia were better able to comprehend high than low imageability words. Patients have also been described who show impaired auditory comprehension of abstract but not concrete words, despite being able to comprehend both types of word when presented in written form, and being able to recognise both concrete and abstract words in auditory lexical decision (Franklin, Howard, & Patterson 1994). Occasionally patients have been reported who are better able to comprehend abstract than concrete words in both auditory and reading tasks (Warrington 1975), or whose auditory comprehension deficits affect only certain semantic categories, such as body parts (Goodglass & Budin 1988), or objects (Warrington & McCarthy 1983).

If lexical-semantic representations do influence earlier stages of acoustic-phonetic processing, as some researchers have suggested, then it is important to consider how such deficits might influence the semantic information available to the listener. For instance, aphasic listeners who have difficulty accessing the meanings of abstract words might show an imageability effect in the facilitation of early auditory processing, or listeners whose comprehension is affected by semantic category might show category specific effects on speech perception. The availability of semantic representations will be considered in relation to the effects of imageability on spoken word recognition (chapter four), and of picture contexts on phoneme discrimination (chapters five and six).

Semantic context effects

The comprehension of spoken words is influenced not only by semantic attributes of the words themselves, but also by the semantic context in which they are heard. Preceding words or sentences might provide such contexts, and this is likely to have great importance for functional comprehension. For instance, the ability to predict lexical-semantic candidates whilst listening to connected speech might assist auditory processing both for normal listeners under difficult listening conditions, and for aphasic listeners with impaired speech perception. Prediction processes could be supported by the fact that much everyday language is predictable, since people often converse and exchange information in predictable ways. Speakers may rely on a narrow range of language when talking about a particular topic, allowing the listener to narrow down expectations about what is likely to be said (Brown 1990 pp.151-152).

A key question in the literature is whether prior semantic contexts actually determine which words and meanings become activated, or whether their effects are limited to processes of selection between competing candidates. Some interesting findings related to this question have come from investigations of lexical ambiguity resolution. Swinney investigated whether semantically biasing sentence contexts were able to restrict the initial activation of word meanings to those that were contextually plausible, or whether context served only to select between meanings that had been activated (Swinney 1979). He used a cross-modal priming task, in which participants heard two spoken sentences, the second of which contained a lexically ambiguous word. Participants were instructed to make a lexical decision on a written word that was presented either simultaneously with the offset of the ambiguous word, or after a delay of four syllables. Lexical decision items were either unrelated to the ambiguous word, related to the contextually appropriate meaning, or related to the contextually inappropriate meaning. So for example, participants heard the context:

'Rumor had it that, for years, the government building had been plagued with problems. The man was not surprised when he found several spiders, roaches, and other bugs in the corner of his room.'

Listeners were asked to make lexical decisions on one of the written words ANT, SPY or SEW. If sentence context restricted the activation of word meanings, it was predicted that only the word ANT should be facilitated compared to the unrelated word SEW, since ANT is related to the appropriate meaning of '*bugs*' in this context. If, however, sentence context influenced only the selection between meanings that were already activated, then both ANT and SPY should be facilitated since both are related to alternative meanings of '*bugs*'. The results demonstrated that sentence contexts facilitated activation of both these meanings for targets presented simultaneously with the offset of '*bugs*', but that four syllables later only the contextually appropriate meaning speeded the lexical decision. This was interpreted as evidence that all word meanings are automatically activated when a word is heard, irrespective of how well they fit with the semantic context, but that activation of contextually inappropriate meanings is quickly suppressed. In a similar study, the effect of congruence with preceding sentence contexts on facilitation of written lexical decisions was explored (Fischler & Bloom 1979). However, in this experiment more than one test word was contextually appropriate, with one being much more likely in the context of the preceding sentence. So for example, participants would read the incomplete sentence prime: *'She cleaned the dirt from her...'*, and were asked to make a lexical decision half a second later on one of the written words SHOES, HANDS or TERMS. While both SHOES and HANDS were contextually appropriate, SHOES was considered the more likely completion of the prime sentence. The results showed that only the most likely words were primed. Although this finding appears to conflict with that of Swinney, there are key differences between the experiments that could account for this. One of these is that the type of semantic relations tested in the two studies are of a different nature. Also, Fischler & Bloom's study imposed a delay between presentation of the priming context and of the lexical decision target, making it possible that early effects of context at the prime offset may have been overlooked.

The importance of Swinney's study is that it indicates that sentence contexts do not determine early, automatic access to semantic representations, but rather assist in the selection of the most appropriate candidate. Further support for this notion comes from another cross-modal priming experiment that used biasing sentence contexts (Zwitserlood 1989). In this study the lexical decision target was presented either before or after the uniqueness point of the probe word, in order to further explore the time-course of lexical activation. Sentence contexts strongly biased just one of the lexical candidates within the cohort of words that were compatible with the initial fragment of the probe word. Words presented for lexical decision were semantically related either to the contextually favoured lexical candidate, or to a contextually inappropriate competitor. It was found that words related to either candidate were facilitated prior to the uniqueness point, indicating that the sentence context did not suppress activation of the inappropriate word. However, after the probe's uniqueness point, only those words related to the contextually appropriate candidate were facilitated. This seems to confirm that, at least for normal listeners, sentence contexts facilitate comprehension only after a word has been uniquely identified.

A number of studies have, however, claimed that word comprehension in aphasia is facilitated by sentence context. For instance, a patient with word sound deafness discussed earlier showed considerably better auditory comprehension when the range of speech stimuli was contextually constrained by the carrier sentence (Saffran, Marin, & Yeni-Komshian 1976). When asked to identify a spoken word from an array of written words that included the target word and two phonological foils, the patient was more accurate in identifying words presented at the end of a sentence than words presented in isolation. Several studies have claimed that providing redundant contextual information improves aphasic comprehension of words in sentences. For instance, Clark & Flowers (1987) found that the question 'Which one is the book that you read?' was responded to more accurately than either 'Which one is the book ?' or 'Which is the one you read ?'. Prior sentence contexts and picture contexts have been shown to improve comprehension both of target sentences and of specific lexical items (Pierce & Beekman 1985). For instance, when the predictive context 'The girl was crying' preceded the target sentence 'The girl was peeling an onion', participants were better able to respond to the question 'What was she peeling?'. Pierce (1988) showed that this was also true when the contextual information followed the target, but that the same effect was not achieved by simply repeating the target sentence.

However, not all studies have shown facilitatory effects of sentence contexts. Pierce & Destefano (1987) assessed auditory comprehension of target words by a group of aphasic listeners. They explored the interaction between the degree to which a narrative predicted a target word, and the amount of the word that was presented. Participants were presented with narratives that predicted a specific target word to a greater or lesser extent. The target word in each narrative was either presented in full, or only the initial consonant and vowel were presented. Participants were then asked a question related to the target word and asked to point to the correct word from a choice of four written words. These words included the target, a contextually appropriate semantic foil, a contextually inappropriate phonological foil, and an unrelated foil. The results showed that listeners used information both from the context and from the auditory signal, but that a predictive context took precedence over the auditory input. In the low predictive context condition, participants were usually able to accurately identify the intact target word, but made many semantic errors when they heard only the initial fragment of the word. This suggested that they were relying more heavily on the semantic context than on the partial acoustic information. In the high predictive context condition, participants actually made more errors than in the low context condition for both intact target words and initial fragments. Most of these errors were again semantic, suggesting reliance on context rather than acoustic information even when the acoustic information available was complete and unambiguous. The authors comment that this finding was unexpected, since other studies have shown facilitatory effects of sentence contexts on aphasic comprehension. They suggest that the reason for these conflicting results is that their study included semantically related foils, whereas others (e.g. Pierce & Beekman 1985) typically did not. This account holds true also for the apparently conflicting results of Saffran et al. (1976), whose task included only phonological foils, and suggests that the facilitatory effect they described may have been operating at a semantic rather than a phonological level. Further, since all of these studies required responses involving non-auditory modalities (i.e. written word selection) it remains unclear whether the contextual effects reported were really specific to auditory processing. In order to determine this, tasks are needed that require judgements only about auditory input.

In summary, it has been shown that comprehension of an individual word can be influenced both by the semantic attributes of the word itself (such as imageability and concreteness/abstractness), and by the semantic context in which the word is heard. It has also been demonstrated that semantic representations influence spoken word recognition. In order to consider whether lexical and semantic contexts influence phonological encoding, it is therefore important also to consider whether lexical access is influenced by semantic context in our participants. An experiment will be presented in chapter four that explores interactions between word imageability and sentence context in spoken word recognition. The results of that experiment will contribute to interpretation of the findings on phoneme discrimination experiments presented in chapters five and six. Before these are considered, a number of theoretical models of auditory processing will be introduced.

Theoretical Models

Any account of the processes involved in mapping from an acoustic signal onto a word meaning must rely on theoretical assumptions about the nature of the processing system. Many alternative models of auditory speech processing have been suggested. These tend to share certain features, such as the assumption that there are different levels of representation (for instance phonetic, phonological and semantic), and that information maps between these levels via sets of connections. However, the models vary in a number of important ways. These include the degree to which the processing mechanisms are made explicit, the nature of the representations within each level, the directionality of information flow between levels, the presence or absence of connections between representations within a level, and whether connections are facilitatory, inhibitory, or a combination of both. One account, the Cohort Model of Marslen-Wilson and colleagues, was briefly introduced in relation to spoken word recognition processes. In this section, several other types of model will be introduced and contrasted. These include examples of cognitive neuropsychological, localist connectionist and distributed connectionist models. The implications of each of these models for the effects of context on speech discrimination and word recognition will be considered briefly here, and again in more detail in chapter seven.

One type of model that has been very influential, particularly in clinical practice, is the cognitive neuropsychological model. There are a number of versions of this model, each of which consists of a series of highly modular processing components with connections between them (e.g. Ellis & Young 1988; Ellis & Young 1996; Kay, Lesser, & Coltheart 1992). One major limitation of the cognitive neuropsychological models is that they lack detailed specification of either the nature of the representations within each module, or of the processing mechanisms by which representations map onto each other. (The implications of this under-specification for interpretation of experimental findings will be considered in more depth in chapter seven). The model proposed by Kay, Lesser & Coltheart forms part of the introduction to the PALPA assessment battery, and is widely used as the basis for clinical assessment of aphasia. It also underpins recent research into the treatment of auditory processing disorders in aphasia (Francis, Riddoch, & Humphreys 2001). In this model, the speech signal first undergoes auditory analysis, phonological buffering, and matching to a phonological word representation before meaning can be accessed (see Figure 1).

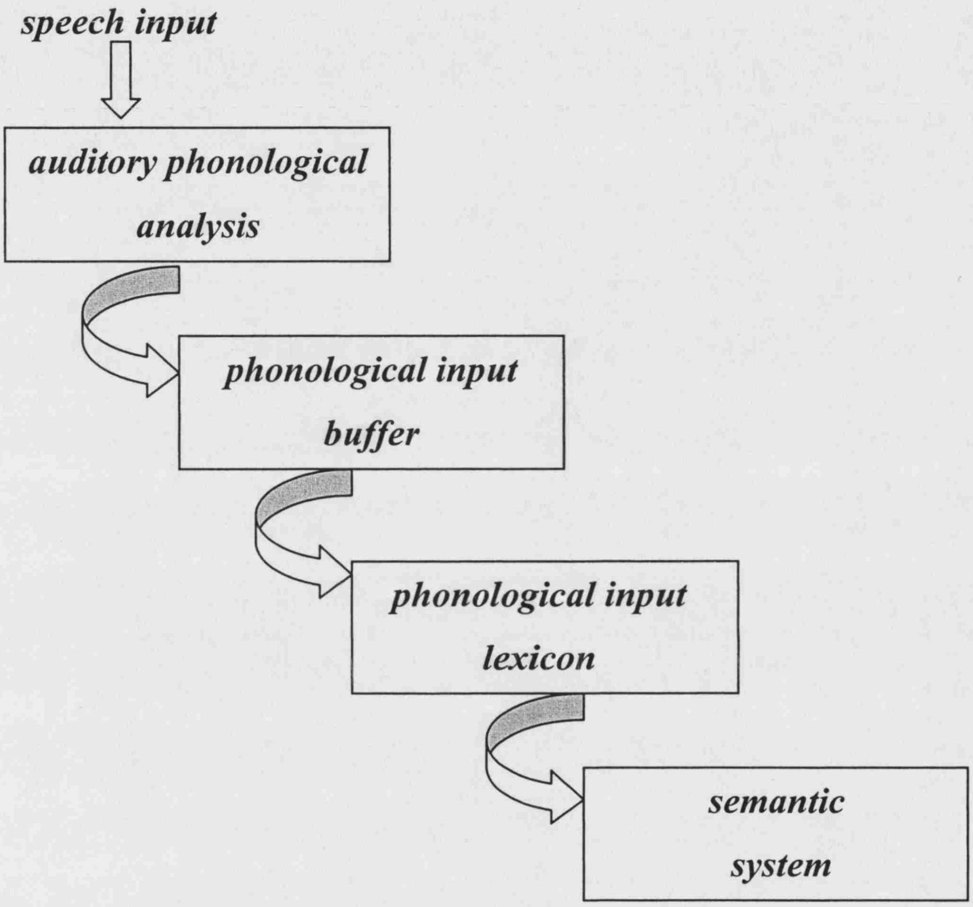

Figure 1. Serial model of auditory processing (from Kay, Lesser, & Coltheart 1992 p.15)

This model is conceptually fairly straightforward, and is able to account for many findings in the literature. For instance, the distinct symptoms of word-sound deafness, word-form deafness and word-meaning deafness described by Franklin (1989) can be explained in terms of discrete processing impairments at the stages of auditory phonological analysis, access to the phonological input lexicon, and access to the semantic system respectively. However, there are other findings that do not fit so easily with this theoretical account. These include the findings that semantic priming can reduce normal reaction times in auditory lexical decision, and that some aphasic listeners display an imageability effect in auditory lexical decision. According to the model, lexical decisions are made at the level of the phonological input lexicon before the semantic system has been accessed. As the route from the phonological input lexicon to the semantic system is uni-directional, there is no means by which semantic representations could influence access to the phonological input lexicon.

An alternative version of this model that incorporates a route by which semantic information can be fed back to the phonological input lexicon has been proposed (e.g. Ellis & Young 1988; Ellis & Young 1996; Lesser & Milroy 1993). These authors suggest that the route between the phonological input lexicon and the semantic system should be bi-directional; just as word forms activate word meanings, word meanings also activate word forms (see figure 2).

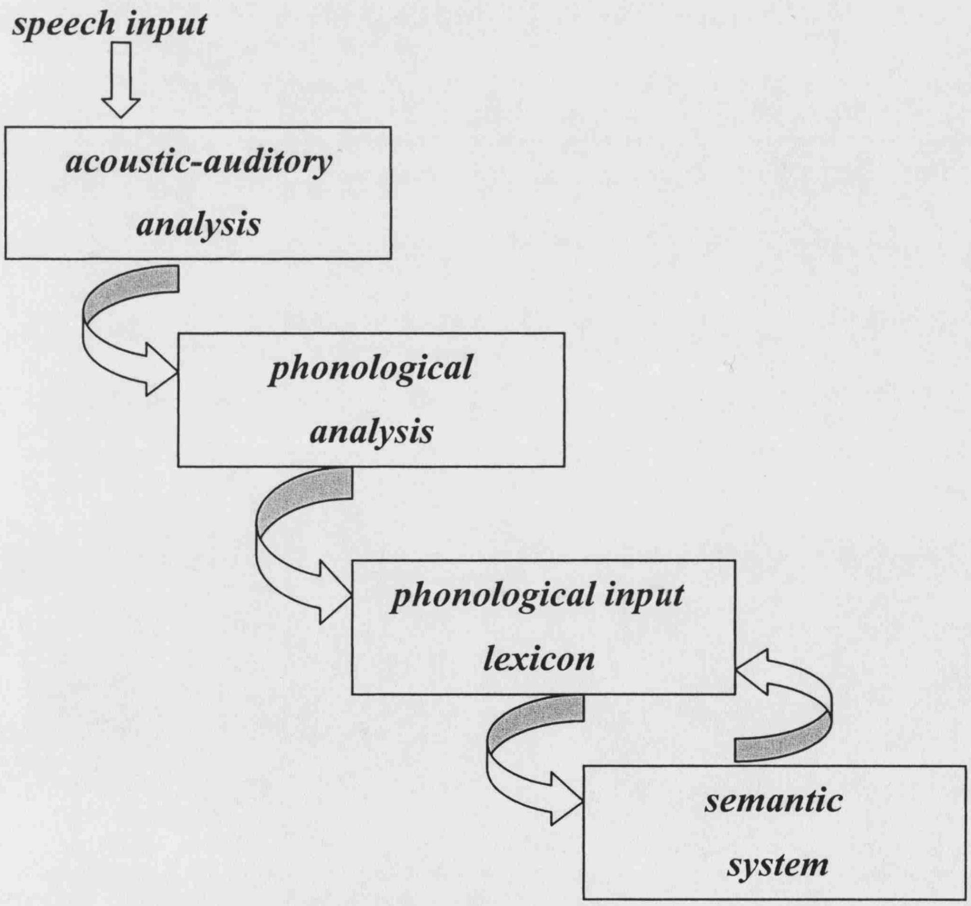

Figure 2. Interactive model of auditory speech processing (from Ellis & Young 1988)

This type of model has been described as an interactive parallel model (Marslen-Wilson & Tyler 1980), and as a spreading activation or interactive activation model (Aitchison 1987 p.173). Under this account, all possible interpretations of the acoustic signal will be aroused in the phonological input lexicon and transmitted to the semantic system; compatible semantic interpretations will be aroused and fed back to the phonological input lexicon. Thus multiple representations may be activated at both levels and processed in parallel whilst interacting with each other. As information flows back and forth, certain representations receive increasing activation (through weighting mechanisms which are not specified), while others lose activation and return towards resting levels. At a certain point, one word form reaches its activation threshold and the word is recognised. This interactive model is potentially able to cope with both semantic priming effects and imageability effects in auditory lexical decision. High levels of semantic activation resulting either from a related word prime, or from a high level of imageability, will facilitate recognition of associated word forms.

The model still presupposes that auditory-phonological analysis must be completed without any downward flow of higher-level information. This requires that the speech input be acoustically unambiguous, as an adequate auditory-phonological representation must be passed on to the phonological input lexicon in order for word recognition to take place. However, words can be recognised with only minimal acoustic information provided the semantic context is strong enough to narrow down expectations. This model also predicts that an aphasic person who has difficulty with phoneme discrimination should perform poorly on auditory lexical decision and auditory comprehension tasks. This is because the auditory-phonological analysis will output incomplete or inaccurate representations to the phonological input lexicon, which has no mechanism by which to signal that a reanalysis is required. This does not match the findings in the literature that speech discrimination, word recognition and auditory comprehension are at least partially dissociable in aphasia. In a revised version of their model, Ellis & Young (1996) included a bidirectional route between the phonological input lexicon and the phonological analysis system. Some implications and limitations of this additional processing route will be considered in chapter seven.

The cognitive neuropsychological approach has been criticised for the tendency of researchers to focus in detail on one processing subcomponent at a time, rather than exploring the processing system as a whole including the interactions between components (Tyler 1992b pp.261-66). Some authors, particularly those working within the connectionist tradition, have proposed much more strongly interactive models of auditory processing that are able to recognise acoustically degraded speech. In some of these, every component in the system is able to communicate with, and influence the processing of, every other component. This allows for interactions not only between word forms and meanings, but also between word forms and phonemes, and in some cases between word meanings and phonemes. For instance, the HEARSAY-II computational system uses a global database - the blackboard - which receives the output of all the other components (Erman, Hates-Roth, Lesser & Reddy 1980). These include acoustic-phonetic, phonological, lexical and semantic representations A centralised control mechanism inspects all the representations input to the blackboard, and formulates a hypothesis as to the most likely lexical candidate to account for the data. This hypothesis is fed back to the sub-components that can then add to, delete or modify their entries on the blackboard. This process continues until a single word representation reaches its activation threshold, and word identification takes place. While such a strongly interactive model has been shown to recognise degraded input, it was not designed to account accurately for psychological data. Other designers of connectionist models have attempted to simulate experimental evidence of human speech perception more closely. Probably the best known of these is the TRACE model (Elman & McClelland 1986; McClelland & Elman 1986). This model, which is related to the interactive activation model of word reading (McClelland & Rumelhart 1981), incorporates three levels of representation corresponding to acoustic-phonetic features, phonemes and words. Within each level are a number of local units corresponding to the range of features, phonemes and words that the system is able to recognise. Feature units have bi-directional excitatory connections to phonemes that they are part of, while phoneme units similarly have bi-directional excitatory connections to word units that they are part of (see Figure 3). In addition to these excitatory connections between levels, there are also inhibitory connections between units within the phoneme level, and between units within the word level.

Input to the system, in the form of mock-speech featural representations, activates the corresponding feature units. These in turn activate the corresponding phoneme units, which try to suppress competing phonemes through their lateral connections. Active phonemes activate corresponding word units, which also try laterally to suppress competing words. Units at higher levels that are active send activation back to corresponding units at lower levels, thus further increasing activation of those

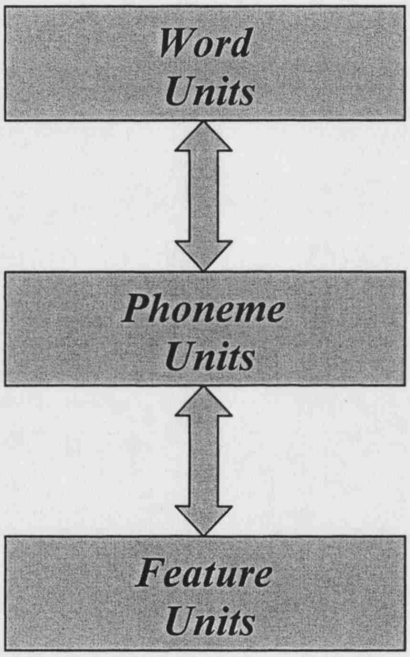

Figure 3. The TRACE model of auditory speech processing (adapted from McClelland & Elman 1986)

units; so an active word increases activation in its constituent phonemes, and an active phoneme increases activation in its constituent features. As more of the word is processed and as cycles of processing continue, candidates at the phoneme and word levels that provide the best fit gradually become isolated from other candidates whose activation is suppressed. When only one word unit remains active the system stabilises, and at that point the word is 'recognised'. Word recognition can still take place in TRACE when output from the feature level is impoverished (for instance due to a degraded acoustic signal or a simulated impairment in auditory analysis), provided there is sufficient phonemic and lexical activation to drive the system.

McClelland & Elman demonstrated that the TRACE model could simulate a number of key findings from psychological studies of speech perception. For instance, categorical perception arises naturally within the model from the inhibitory connections between phonemes. If the input activates both /b/ and /p/ units at the phoneme level, these units compete with each other. Whichever of these has received the strongest activation from the feature level will exert the greatest inhibitory effect. As cycles of processing continue this inhibition increases and leads to a sharp discrimination boundary between the two phonemes, similar to the categorical boundary in human speech perception. TRACE also accounts for some effects of lexicality on phoneme discrimination. The top-down excitatory connections between word and phoneme units result in stronger activation of phonemes that are constituents of active words. This effect increases with later-occurring phonemes, since the strength of feedback activation accrues over time as more of the word is processed, resulting in faster recognition of late occurring phonemes in words than in nonwords in phoneme monitoring tasks. This facilitatory feedback, in combination with the lateral inhibitory connections between phonemes, also results in an increased probability that ambiguous phonemes will be categorised as being constituents of words than of nonwords; thus TRACE emulates the word superiority effect demonstrated experimentally in human listeners.

However, a number of researchers have also reported experimental findings that are at odds with TRACE's account of speech perception (see Ellis & Humphreys 1999 chapter six for a review). For instance, the claim from TRACE's authors that lexical representations have inhibitory connections to phonemes that they do not contain has been questioned (Frauenfelder, Segui, & Dijkstra 1990). These authors used a phoneme monitoring task to explore lexical inhibition of phoneme representations. They compared French listeners' reaction times to phonemes in nonwords that shared onsets with words e.g. **vocabutaire*, with reactions to the same phoneme in nonwords that did not share onsets with words e.g. **socabutaire*. In **vocabutaire*, the /t/ phoneme occurs after the recognition point for the word *vocabulaire*. According to TRACE, the word *vocabulaire* should be selected before the non-congruent /t/ phoneme is processed. The lexical representation of *vocabulaire* should therefore inhibit the phoneme /t/ and facilitate the phoneme /l/. This should result in slower reactions to the /t/ in **vocabutaire* than in **socabutaire* for which no word representations should be selected. However, Frauenfelder et al found no evidence of such inhibition.

TRACE also fails to take account of the relationship between local phonological context and stimulus discriminability (Massaro 1989). Massaro used phonemes which varied continuously between /r/ and /l/. He asked listeners to discriminate between them when the signals were embedded in contexts that favoured one or the other in relation to the permissible phonological strings in English. For instance, the context /s_i/ favours /l/ while /t_i/ favours /r/, and /p_i/ favours neither. Massaro found that listeners were more likely to perceive that phoneme which was favoured by the phonological context. This finding is not captured by TRACE. TRACE has also been criticised for assuming that the effects of top-down feedback are too powerful. In TRACE the feedback from words to phonemes occurs whether or not the input is ambiguous or degraded (although the effects of this feedback should be greater for degraded than intact input). However, several researchers have shown that the biasing effect of a word context on the processing of phonemes is only apparent when the input is either ambiguous or acoustically degraded (e.g. Connine & Clifton 1987; McQueen 1991).

A further limitation of models such as TRACE, which are based on discrete local units as representations of words, is the psychological implausibility that there are discrete localist representations of words in the human brain. Brain imaging studies have revealed that tasks involving perception or production of meaningful words result in widespread cortical activity (see Pulvermuller 2001 for a review). Areas of activation relate not only to word forms, but also to word meanings. For instance, most concrete nouns produce activation in both visual and motor cortices, presumably due to their perceptual and action associations (Pulvermuller 2001, p 521). These findings relate to the concept of 'distributed representations' in which concepts are represented as patterns of activity over a network of connected units, and interactions between conceptual representations are "generated by millions of simultaneous interactions at the level of their microstructures" (Hinton 1981 pp.161-

162). Hinton argued that such distributed representations constituted a more realistic model than localist representations of how concepts are represented in the nervous system. The notion that words are represented in a distributed manner forms a key assumption of the last model of auditory speech processing that will be introduced here: the Distributed Cohort Model (Gaskell & Marslen-Wilson 1997).

The Distributed Cohort Model is an interactive connectionist network designed to map featural representations of speech onto phonological-semantic representations of words (see Figure 5). Within the Distributed Cohort Model, lexical access operates on a single distributed representation, not on activation of a number of separate representations at different levels. This account is thus fundamentally different to both the cognitive neuropsychological and the localist connectionist models that have been considered so far. Representation of a word is assumed by the authors to be a distributed pattern encompassing phonological, morphological, semantic and syntactic specification (although only the phonological and semantic domains are implemented). Activation of a single complete lexical representation involves setting the correct values across the network for all the output representational units. The network can hold multiple hypotheses as to the identity of a word prior to the uniqueness point; at each stage up to the uniqueness point the model's output is a blend of all the competing word hypotheses.

The network takes a mock-speech representation, rather than real speech, as its input. The acoustic signal is represented as the output of a set of eleven binary units corresponding to Jakobson, Fant and Halle's (1952) system of phonetic features. Perceptual information from these units is passed through a set of hidden units, which have bi-directional connections to a set of 'context units' that store the previous time-step. These context units constitute a memory buffer that carries information about both phonology and semantics simultaneously. The context units allow the network to modify its output, by comparing and moving it closer to the learned representations of words, using standard backpropagation (Rumelhart, Hinton, & Williams 1986) (see chapter seven for a more detailed account of this processing). The hidden units send activation simultaneously to two sets of output units, corresponding to phonological and semantic representations. This simultaneous output means that there are no discrete phonological and semantic stages of processing. Differences in the speed or accuracy of word recognition and comprehension are modelled by the partial activation of a distributed representation. The activation of a word is inversely related to the distance between the output of the model and that word's representation. i.e. the closer the values of the output to the word's values across all the nodes in the network, the more highly activated the word is. When there is no distance (or difference) between the output values and a single word's values, the model has uniquely recognised that word.

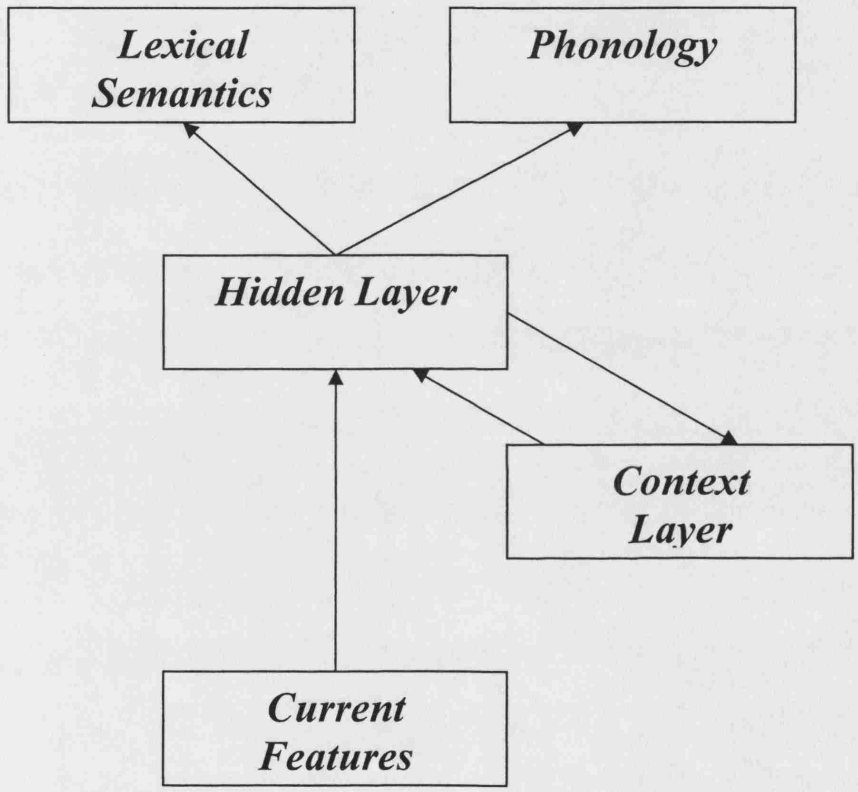

Figure 4. Distributed model of auditory speech processing (from Gaskell & Marslen-Wilson 1997 p.617)

The semantic output nodes are not intended to be a realistic representation of semantic knowledge. Instead, they consist of a random pattern of binary nodes each set to either zero or one. These nodes could presumably map onto a binary semantic feature model of representation where each node represents a feature such as animate or female (Katz & Fodor 1963), although this is not specified. There are a number of drawbacks to such a simplistic account of semantic representation. For example, binary features do not easily capture many aspects of word meaning, such as sense-continua and prototypicality. Semantic factors such as imageability are not represented, nor are semantic relationships between words (such as category membership and superordinate/subordinate relations) captured. The limitations of the model's semantic representations will be discussed further in chapter seven.

The Distributed Cohort Model is able to account for a range of experimental findings on human speech perception. For instance, the network is able to activate word-endings that are compatible with a word-initial fragment, much as human listeners have been shown to do in gating tasks. This is because the network's hidden units attempt to map the input immediately onto representations of whole words; while featural information strongly activates phonological representation of that portion of a word that has been input, the distributed phonological-semantic representation that is activated includes weaker activation of the remaining portion. Thus word recognition can take place at the uniqueness point, rather than requiring the acoustic information related to the entire word to be processed. The processes by which the network adjusts its output towards active word hypotheses is weighted by the number of times those words were encountered during training. The network is more likely to stabilise, and stabilises more quickly, on words that were encountered more often during training. The model thus emulates the effects of word frequency in human listeners.

The authors also present evidence that the network performs similarly to humans in a range of phonetic and lexical decision tasks, using input that contains mismatching featural cues between the vowel and the subsequent consonant. These experiments were designed to test sensitivity to coarticulatory acoustic cues in the input, and illustrated that both the model and the participants showed interference between the lexical sources of the mismatching segments. The fact that human listeners show effects of neighbourhood density on speed of word recognition is accounted for explicitly by the Distributed Cohort Model. Such effects arise naturally from the process of competition between multiple active hypotheses as to a word's identity; the more hypotheses are active, the further the model's output will be from any individual word. This is because all the active hypotheses are represented simultaneously across the same network units. Finally, the authors discuss how the model could account for the effects on word recognition of linguistic contexts such as semantic primes. The semantic activation produced by a prime could influence the competition process in the model in much the same way as implemented for word frequency. That is, the presence of a prime would draw the model's output towards related word representations, thus speeding recognition of primed words. The processes by which the network handles competition between words are important to interpretation of experimental findings in the current study, and will be discussed in more detail in chapter seven.

Summary of introduction

In this chapter, some key findings in the literature related to the mapping from acoustic signals onto word forms and meanings have been discussed. Evidence has been drawn from both normal and aphasic listeners, and has included discussion of ways that higher level representations appear to influence speech discrimination and word recognition. Alternative theoretical accounts of the data have been introduced, and some of their implications for the effects of lexical and semantic contexts on speech perception have been contrasted. It has been demonstrated that the standard cognitive neuropsychological models that underpin much clinical practice and literature do not easily account for some aspects of the evidence.

Many questions about the nature of the systems that underlie normal and aphasic auditory processing remain unanswered. A series of related experiments was designed to explore some of the interactions between representational levels. These interactions include the relationship between word recognition, imageability, and sentence context; the relationship between phonological encoding and lexical context; and the relationship between phonological encoding and pictorial semantic contexts. The design of these experiments will be described in chapter two. Detailed profiles of the aphasic participants are presented in chapter three, with experimental results from both aphasic participants and controls discussed in chapters four, five and six. The implications of the findings for theoretical models of auditory processing will be discussed in chapter seven, where it will be argued that accounts of impaired processing in aphasia should be based on an interactive model that incorporates distributed representations.

Chapter 2 Experimental Design and Methodology

The auditory processing of five aphasic participants and ten controls was investigated in a series of related experiments. These experiments utilised phoneme discrimination and lexical decision paradigms to explore the influence of lexical, pictorial, and sentential contexts on speech discrimination and word recognition. A detailed profile of the language processing abilities and impairments of each aphasic participant was obtained to assist interpretation of experimental results. In each experiment both accuracy and reaction time data were collected, with the effects of phonetic and lexical factors being explored under different context conditions.

Ethical approval for this study was granted by the Joint University College London / University College London Hospitals Committees on the Ethics of Human Research (Study no. 99/0236).

Recruitment of Participants

Participants volunteered to take part in the study and were paid a £5.00 honorarium per session.

Ten healthy controls were recruited, all adult monolingual native speakers of British English. All reported no current or previous history of speech or language impairment, and had average hearing thresholds[10] better than 40dB HL on pure tone

[10] The cut-off point for hearing thresholds was the same for control and aphasic participants in order for comparisons between the two groups to be made. Since aphasic participants were more likely to be drawn from an older age range (e.g. 50-80 years), the hearing levels were intended to be realistic for this population whilst ensuring that test stimuli played free-field at comfortable listening levels would be audible. However, it is recognised with hindsight, and in recognition of the actual age range and audiometric results of participants recruited, that a more stringent cut-off could have been applied. This would have had the advantage of ruling out the possibility that high frequency hearing loss in some of the participants might have contributed to error rates.

audiometry over 1-4 kHz. The group consisted of six males and four females aged between 37 and 63 years (with a mean age of 49 years). Control group volunteers were recruited by means of an advertisement (Appendix 1) which was distributed via notice boards at University College London, and at a number of community locations. Volunteers were provided with a copy of the Volunteer's Information Sheet (Appendix 2). After reading this, each volunteer was given an opportunity to ask further questions of one of the researchers before completing the consent form (Appendix 3).

Five aphasic participants were recruited to the study. They were all adult native speakers of English, and with the exception of one (TDS) were monolingual British English speakers. Aphasic participants were all referred with a diagnosis of acquired aphasia resulting from stroke, and were at least six months post onset of aphasia. Each aphasic participant had been identified by the referrer as showing evidence of an auditory processing impairment. Referrers stated that there was no indication of significant non-linguistic cognitive impairment in any aphasic participant.

An advertisement requesting referral of aphasic participants (Appendix 4) was circulated to members of the British Aphasiology Society, an organisation whose membership consists of clinicians and researchers involved in the study and/or treatment of aphasia. As a result of this, eight people were initially referred to the study. All referrers were practising Speech and Language Therapists. A more detailed research protocol (Appendix 5) together with a copy of the Participant Information Leaflet (Appendix 6) was sent to all referring clinicians. Referring clinicians were requested to discuss this information with the aphasic person using whatever strategies best supported that person's comprehension, to seek permission of the client for the referral, and to provide the researcher with written documentation relating to their client's language impairment. This documentation included (if available) medical reports, speech and language therapy reports, results of language and neuropsychological assessments and information about therapeutic interventions aimed at addressing the language impairment and/or communication disability.

The researcher then discussed the study with the aphasic volunteer using supported communication appropriate to individual needs (Kagan 1995; Lawson & Fawcus 1999). Consent to participate in the study was obtained and recorded on a consent form adapted to the needs of aphasic people (Appendix 3).

A screening assessment of hearing and auditory processing (see below) was carried out in a single session. Five of the eight aphasic volunteers met all the selection criteria and were recruited onto the study. Two volunteers were excluded because their hearing levels exceeded the inclusion criterion, and a third because he exhibited difficulty in using the response box due to limb dyspraxia. The final group of aphasic participants is summarised in Table 2.

Method

Summary of method

An initial screening session was carried out to ascertain that participants met the inclusion criteria for participation. For all volunteers this involved a hearing test, and the aphasic volunteers additionally carried out two tests of auditory processing to confirm the diagnosis of an auditory processing impairment.

Aphasic participants then participated in a detailed assessment of language processing. This took approximately eight sessions over a three-week period. The purpose of this assessment was to obtain a profile of each aphasic participant's language processing skills and impairments in input and output modalities (Tyler 1992b pp 264-5). Following this stage of assessment there was a break of approximately two weeks to allow for preliminary analysis of assessment findings before commencement of experimental testing.

Aphasic and control participants then participated in three experiments to explore their auditory language processing. Experimental testing was carried out over approximately six hour-long sessions for aphasic participants and five hour-long sessions for controls, spread over a three to four week period. The first experiment explored the effects of word frequency, word imageability, and predictive sentence contexts on word recognition, using both a standard auditory lexical decision task and a sentence-context lexical decision task. The second experiment explored the relationship between phonetic encoding and lexical context using nonword and word minimal pair judgement tasks, while the third experiment explored the effects of a semantic context provided by a picture on phoneme discrimination using a picture-word verification task.

Both accuracy and reaction time data were collected in order to achieve the greatest test sensitivity (particularly for the control group) together with the greatest test reliability (particularly for the aphasic participants) (Mackersie, Neuman, & Levitt 1999).

Audiometric Screening

All participants underwent audiometric screening prior to acceptance onto the study to reduce the possibility that performance on measures of auditory language processing might be confounded by sensory impairment[11]. Screening involved pure tone air-conduction audiometry using an Amplivox Model 116 Audiometer, carried

[11] It should be pointed out that, apart from pure tone audiometry, no assessments of pre-phonetic auditory processing were carried out. This decision was taken in light of the already extensive schedule of testing required of each participant, which extended beyond those tests reported in this thesis. Nevertheless, it is recognised that inclusion of tests such as environmental sound recognition, temporal order judgement using pure tones, click-fusion, and dichotic listening using non-speech stimuli would have provided useful evidence of wider aspects of auditory processing. This would have contributed to a more detailed understanding of the speech perception deficits in the aphasic participants, as in the work of other authors (such as Morris et al., 1996; Praamstra, 2001; Auerbach, 1982).

out in a quiet (but not sound-proofed) room. Tones were presented monoaurally to left and right ears via Amplivox 'Audiocups' noise-excluding earshells. Hearing thresholds were determined at 1 kHz, 2 kHz, and 4 kHz and were manually recorded on an audiogram. The mean threshold over these three measurements was calculated to determine the average hearing level.

The cut-off point for inclusion in the study was an average hearing level of 40 dB. It should be noted that this cut-off point is higher than the widely accepted standard of 20 dB used to determine whether hearing levels are normal. The higher cut-off of 40 dB was set since aphasic volunteers were most likely to be drawn from an older population. A cut-off of 20 dB was considered likely to exclude a large proportion of potential volunteers, who might nonetheless be able to accurately hear speech stimuli presented at a comfortable listening level in a quiet room. Nevertheless, it must be recognised that some participants were included in the study despite exhibiting a mild hearing loss. This was taken into account in consideration of experimental results.

Results of audiometric screening for controls are presented in Appendix 7, and for aphasic participants within the individual profiles in chapter three.

Screening of Auditory Language Processing

All aphasic volunteers who had passed the audiometric screening carried out two further screening assessments of auditory processing. These were Simple Auditory Lexical Decision (described in chapter four), and Nonword Minimal Pair Discrimination (described in chapter five).

The rationale for these screening assessments was:

1. To confirm the diagnosis of an auditory processing impairment, defined as a score at least three standard deviations below the control mean on at least one of

the two screening assessments. Normative accuracy data was collected from the ten controls that took part in this study.

On the simple auditory lexical decision task the controls' mean score was 97% (range = 93-99% raw score range = 149/160 – 159/160 SD = .172). The cut-off point for aphasic participants of three standard deviations below the control mean was 92%.

On the nonword discrimination task controls had a mean score of 98% (range = 96-99% raw score range = 123/128 - 127/128 SD = .149). The cut off point for aphasic participants of three standard deviations below the control mean was 93%.

2. To assess whether the volunteer would be able to co-operate with the experimental test procedures. This was important since some volunteers might be precluded from participation due to stroke sequelae such as neuro-muscular or motor programming disorders affecting their ability to respond using the button-response box.

3. To assist the volunteer to come to a clear understanding about the nature of the testing involved in the study. Potential aphasic volunteers would be almost certain to have difficulty in understanding spoken language, and likely also to have difficulty in understanding written language. Practical experience of carrying out a task was considered a more reliable means than explanation alone to ensure that aphasic volunteers genuinely understood what was being requested of them, and thus to make an informed decision about participation in the study.

Results of screening assessments of auditory processing are presented within the individual profiles of aphasic participants in Chapter 3.

Preliminary investigations of language processing in aphasic participants

A detailed profile was obtained of each aphasic participant's abilities across a range of language processing and related tasks. This profile sought to establish individual patterns of sublexical, lexical, semantic and syntactic processing of both spoken and written language, as well as to identify any significant visuo-perceptual impairment. This profile was subsequently used to assist interpretation of individual patterns of performance on experimental measures of auditory processing. Assessments were administered and interpreted by the author, a qualified Speech and Language Therapist with specialist clinical experience of acquired aphasia. Each assessment is described below with the rationale for inclusion, and where it is available normative data is summarised.

Assessment of the visual semantic system

- **Birmingham Object Recognition Battery: Object Decision (B Easy) (Riddoch & Humphreys 1993)**

This task assesses the ability to recognise line drawings of tools and animals. Its use here indicates whether aphasic participants are able to recognise the picture stimuli used in the Picture-Word Verification task of experiment three.

Thirty-two black-and-white line drawings are reproduced, one to a page. The participant is required to look at each item, and indicate whether it represents a real object/animal or an unreal one. Half of the items represent real tools/animals, and half represent unreal ones. The unreal items have been constructed by replacing one part of a picture of a real tool/animal with part of another tool/animal (e.g. a zebra's body with the head of a mouse).

Normative data for 13 control participants aged 50-80 years:

(n = 32 items)   Mean = 30.5   Std.Dev. = 1.4   Range = 28-32

2 Standard Deviations below the control mean = 28

- **Pyramids and Palm Trees (three picture version)** (Howard & Patterson 1992)

This task assesses the ability to access detailed semantic representations from pictures. It was included to indicate whether aphasic participants a) show signs of a significant central semantic impairment, and b) are able to access semantic representations from the picture stimuli in the Picture-Word Verification task.

There are fifty-two items, each of which consists of a triad of line drawings. The participant is required to match the picture at the top of the triad (the given item) to one of two pictures (the target and the distractor) at the bottom of the triad. The choice must be made on the basis of some semantic property or pragmatic association that is shared between the given item and the target. The target and the distractor are always semantic co-ordinates, whereas the given item is usually from a different semantic category.

Normative data for two groups of control participants:

a) Number and ages of control participants not specified :

mean score = 98-99%   errors ranged from 0-3

b) 13 non-brain injured traumatic injury patients aged 18-35 years:

mean score = 98.5%   errors ranged from 0-3

Assessment of situational inference

- **Role Video Test (adapted from Marshall, Pring, & Chiat 1993)**

This task assesses the ability to make predictions about the likely outcomes of video recorded events, and to understand the roles of participants in those events. It was included to identify any non-linguistic event-processing impairment that might impact on a participant's ability to make predictions based on linguistic context.

The first sixteen of the original thirty-two items from Marshall et al. were used. For each item the participant is twice shown a video clip depicting an event. An array of three photographs is then presented, and the participant is asked to select the photograph that depicts the most likely outcome of the event. For example, one video clip shows a woman giving flowers to a man. The participant must select from an array of photographs that depict a) the man holding the flowers, b) the man holding a letter, and c) the woman holding the flowers. In order to select the correct photograph the participant must identify the theme and directionality of the event. In some items the human agent is not visible in the scene, for instance an item showing a knife cutting an apple. The participant must select between photographs of a) a peeled apple, b) a cut apple, and c) a cut orange.

Unpublished data suggests that normal performance is 100% on the thirty-two item test, since five controls made no errors (Jane Marshall, personal communication).

Assessment of single word processing

i) Auditory Input

The following assessments of auditory processing were carried out live, with the author providing the spoken test items. (This is the same voice as was recorded to produce the experimental test stimuli described in chapters four, five and six). Tests were administered in accordance with published instructions, which did not require control of lip reading.

- **Spoken Word to Picture Matching (PALPA 47) (Kay, Lesser, & Coltheart 1992)**

This task assesses semantic comprehension of single words through spoken word to picture matching. It was used to indicate whether participants are able to access specific semantic representations from spoken words that are high in imageability. Any significant difficulty with this task might suggest that participants were unable to generate detailed semantic representations of the spoken words in the Picture-Word Verification task used in experiment three. Without access to the semantic representations of the target stimuli, participants would be unable to make reliable semantic judgements in these tasks.

There are forty items, all highly imageable nouns. For each item the examiner shows the participant an A4 sized page on which are reproduced five black and white line drawings. The examiner then says the target word, and the participant is required to point to the corresponding picture. The drawings consist of a picture of the target word plus four distractors. These are a close semantic distractor from the same superordinate category as the target, a more distant semantic distractor, a visually related distractor and an unrelated distractor. Twenty of the target pictures are both semantically and visually similar to the close semantic distractor (e.g. *crab* and *lobster*). The visually related and unrelated distractors are semantically related to each other (but not to the target).

Normative data for 31 control participants[12]:

(n = 40 items) Mean = 39.29 Std. Dev. = 1.07 Range = 35-40

- **Auditory Synonym Judgements (PALPA 49) (Kay, Lesser, & Coltheart 1992)**

This task assesses the ability to access semantic representations from spoken words, and to judge whether two spoken words are close in meaning. Both high and low imageability words are included in this task, as in the lexical decision tasks of experiment one. In addition, this task gives some indication of participants' ability to hold and compare the representations of two spoken items, a skill necessary for the minimal pair discrimination tasks of experiment two. Poor performance on both auditory synonym judgement and on minimal pair discrimination might suggest a difficulty in the processes of holding and comparing representations, while good performance on either of these tasks would suggest that the participant is able to hold and compare two items.

There are sixty items, each consisting of a pair of words. The examiner says each item, after which the participant is required to judge whether the two words are close in meaning. Half of the items consist of two words that are close in meaning, and the other half consists of two words that are unrelated in meaning. Half of each of these sets consists of word pairs that are highly imageable, and the other half consists of word pairs that are low in imageability. All sets are matched for word frequency.

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[12] Normative data reported here and in relation to other PALPA assessments, with the exception of the two synonym judgement tasks, was published in the PALPA battery (Kay, Lesser & Coltheart 1992). It was obtained from thirty-two non-brain injured subjects, although for some subtests results from fewer than thirty-two controls are provided. Controls were usually the partners of aphasic subjects. The only information about the control group provided by the authors is that they loosely matched the aphasic subjects on age, education and social variables (pp. 18-19). However, no information is provided about the aphasic subjects themselves.

Limited unpublished normative data is available[13] from a group of seven controls aged 66-80 (mean age 73 years):

Total correct	(n=60)	mean 58.43	sd 1.4	range 56-60
High Imageability	(n = 30)	mean 29.29	sd 0.76	range 28-30
Low imageability	(n = 30)	mean 29.14	sd 1.21	range 27-30

- **Auditory Rhyme Judgement[14] (PALPA 15) (Kay, Lesser, & Coltheart 1992)**

In auditory rhyme judgement, participants must hold and compare the phonological representations of two spoken words. The processing requirements of this task are rather closer to the minimal pair judgement tasks of experiment one than is the synonym judgement task described above. If a participant is able to make accurate auditory rhyme judgements this provides evidence that they are able to hold and compare two phonological strings. If a participant nonetheless has difficulty with minimal pair judgements, then it can be inferred that their difficulty is more likely to be in the phonetic encoding or discrimination than in the processes of holding and judging similarity.

The participant hears sixty items, each of which consists of two words. Half of the items consist of two rhyming words, while half consist of two phonologically dissimilar words. Each of these sets is balanced for items where the two words share the same spelling pattern, and items where the two words have different spelling patterns. The participant is asked to indicate for each item whether the two words rhyme.

No normative data are available.

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[13] Control data was kindly provided by Dr Karen Sage of the University of Manchester (personal communication 25th February 2005).

[14] This task was used to replace the written version, after testing of the first two aphasic participants (JW and JWh) revealed that neither was able to carry out the written rhyme judgement task. This decision was made after completion of the profiling assessments with these two participants, therefore the auditory rhyme judgement task was not carried out by them.

ii) Orthographic Input

- **Letter discrimination: Mirror Reversal (PALPA 18) (Kay, Lesser, & Coltheart 1992)**

This task assesses the ability to recognise written letter forms. It was included to assess whether participants were able to carry out sub-lexical processing in the written input modality. It was considered important to determine whether the difficulties that aphasic participants showed in auditory minimal pair judgement reflected a general impairment of sub-lexical processing or were specific to the auditory modality. This task examines the processes involved in mapping visual representations onto segmental orthographic representations, which is in some ways analogous to the mapping from acoustic to phonemic representations in auditory processing.

There are thirty-six items, half of which are correctly formed letters and half of which are mirror-reversed. The participant is required to indicate for each item whether the letter is correctly formed.

Normative data for 25 control participants:

(n = 36 items)   Mean = 35.44

- **Visual Lexical Decision: Imageability and Frequency (PALPA 25) (Kay, Lesser, & Coltheart 1992)**

This task assesses the ability to access lexical representations of written words. It also examines the effects of imageability and word frequency on written word recognition. This task was included to show whether any difficulties that aphasic participants displayed in auditory lexical decision might reflect some general deficit in lexical processing common to both spoken and written input modalities, or whether the difficulty in accessing lexical representations is specific to auditory processing.

There are one hundred and twenty items, each consisting of a letter string. The participant is required to read each item silently, and to judge whether it is a word. Sixty items are words and sixty items are orthographically legal nonwords. The word items are divided into four sets; high imageability-high frequency, high imageability-low frequency, low imageability-high frequency, and low imageability-low frequency. Words are roughly matched across groups for grammatical class, number of letters, number of syllables and number of morphemes. Nonwords are derived from words by changing one or more letters, while preserving orthotactic and phonotactic regularity.

Normative data for 26 control participants showed that accuracy is close to ceiling on both words (mean = 59/60 correct) and nonwords (mean = 59.9/60 correct).

	n	mean	SD
High Imageability High Frequency	15	14.79	0.51
High imageability Low Frequency	15	14.58	0.58
Low Imageability High Frequency	15	14.92	0.41
Low Imageability Low Frequency	15	14.71	0.75
Nonwords	60	59.88	0.45

- **Written Word to Picture Matching (PALPA 48) (Kay, Lesser, & Coltheart 1992)**

This task assesses semantic comprehension of single words through written word to picture matching. It was used to indicate whether any difficulties that aphasic participants might display in accessing semantic representations from spoken words might reflect a general impairment of semantic processing common to spoken and written modalities, or whether the difficulties were specific to the processing of auditory input. If participants were able to access semantic representations from written words, this would confirm that those representations were available within the semantic system. Thus it could be inferred that difficulties shown in Spoken Word to Picture Matching must reflect a difficulty in accessing semantic representations from auditory input.

There are forty items, all nouns. (The same items are used as in PALPA 47 to allow direct comparison). For each item the examiner shows the participant an A4 sized page on which are reproduced five black and white line drawings. The target word is printed at the centre of the array of pictures. The participant is required to read the target word silently and then to point to the corresponding picture. The drawings consist of a picture of the target word plus four distractors. These are a close semantic distractor from the same superordinate category as the target, a more distant semantic distractor, a visually related distractor and an unrelated distractor. Twenty of the target pictures are both semantically and visually similar to the close semantic distractor (e.g. *crab* and *lobster*). The visually related and unrelated distractors are semantically related to each other (but not to the target).

Normative data for 31 control participants:

(n = 40 items) Mean = 39.47 Std. Dev. = 1.01 Range = 35-40

- **Written Synonym Judgement (PALPA 50) (Kay, Lesser, & Coltheart 1992)**

This task assesses the ability to access semantic representations from written words, and to judge whether two written words are close in meaning. As with PALPA 48, it was included to indicate whether any difficulties that aphasic participants might display in accessing semantic representations from spoken words might reflect a general impairment of semantic processing common to spoken and written modalities, or whether the difficulties were specific to the processing of auditory input. As the written synonym judgement task includes low imageability items, it will demonstrate the existence of more subtle semantic processing impairments than can be shown through written word to picture matching alone.

There are sixty items, each consisting of a pair of printed words. (The same items are used as in PALPA 49 to allow comparison between access to semantics from spoken and written words). The participant is required to read each item silently and to tick each pair of words that are close in meaning. Half of the items consist of two words that are close in meaning, and the other half consists of two words that are unrelated in meaning. Half of each of these sets consists of word pairs that are highly imageable, and the other half consists of word pairs that are low in imageability. All sets are matched for word frequency.

Limited unpublished normative data is available[15] from a group of thirteen controls aged 66-94 (mean age 71 years):

Total correct	(n=60)	mean 59.08	sd 1.19	range 56-60
High Imageability	(n = 30)	mean 30	sd 0	range 30
Low imageability	(n = 30)	mean 29.08	sd 1.19	range 26-60

iii) Spoken Output

- **Nonword Reading (PALPA 36) (Kay, Lesser, & Coltheart 1992)**

This task is included to provide information about aphasic participants' access to sublexical phonological representations from non-auditory input. This assists exploration of whether phoneme level deficits are specific to the auditory modality, or whether they are part of broader difficulties with sublexical processing. The results should be considered together with other tests of reading and spoken output, since there are a number of possible reasons for failure on this task.

There are twenty-four items, each a written monosyllabic nonword of three to six letters. All are orthographically legal in English. Participants are asked to try to pronounce each item, and responses are transcribed phonetically. One point is scored for each nonword correctly read.

Normative data for 32 controls:

3 letter (n=6)	mean = 5.77	SD = 0.71
4 letter (n=6)	mean = 5.89	SD = 0.43
5 letter (n=6)	mean = 5.57	SD = 0.9
6 letter (n=6)	mean = 5.65	SD = 0.85

- **Spoken Picture Naming (PALPA 53) (Kay, Lesser, & Coltheart 1992)**

This task is included to provide information about aphasic participants' ability to access lexical forms from a picture-semantic representation, as this may affect performance on the Picture-Word verification task used in experiment three. Impaired performance on spoken picture naming may be attributable to a breakdown in processing at a number of levels (including visuo-perceptual, semantic, lexical and phonemic levels). Individual error patterns must therefore be considered in interpreting naming performance.

There are forty items, each of which is a black and white line drawing of an object or animal. The participant is shown each picture in turn and asked to say its name. Responses are transcribed orthographically, or phonetically in cases of phonemic or neologistic errors. One mark is scored for each item correctly named.

Normative data for twenty-nine control participants:

N = 40 items Mean = 39.8 Std. Dev. = 0.35

[15] Control data was kindly provided by Dr Karen Sage of the University of Manchester (personal communication 25th February 2005).

- **Spoken Event Description (adapted from Marshall, Pring & Chiat (1993))**

This task assesses the ability to produce spoken sentences to describe events. It is included to provide information about participants' access to spoken language beyond the single word level. It may also provide some additional information about how aphasic participants construe events, although difficulties exhibited in this task can reflect impairments at many levels of processing.

There are eight video clips that each portray an unambiguous event. (These clips are items 17-24 of the Role Video Test). In seven of the events the human participants are visible in addition to the instrument and/or theme (e.g. a man sells a camera to a woman). In the remaining item only the theme and instrument of the event are visible (a knife slicing an apple). Each video clip was presented twice before the participant was required to respond. Participants were asked to say what they had seen in the clip. As several of the aphasic participants were known to have severely restricted spoken output, they were instructed that they could also use gestures to supplement their speech in order to convey the message. Verbal responses were transcribed. Any unambiguous or clearly iconic gestures were also recorded in writing.

Normative data was collected from the ten control participants who participated in this study. This was analysed to reveal the types of verbs that were typically used to convey each event, and the ways in which both obligatory and non-obligatory verb arguments were specified. For example, in the descriptions of the role video item 17, in which a man punches a woman, all controls produced a form of one of the verbs *punch* (6)[16], *hit* (3), or *strike* (1). The obligatory actor argument was expressed as either *woman* (6), *her* (2), or *other man* (2), while the obligatory goal argument was expressed by *man* (8) or *he* (2). Half of the controls also produced optional non-arguments with either *in the face* (3), *on the nose* (1) or *in the back garden* (1). Aphasic responses were then described in terms of whether they contained appropriate verbs and their arguments, and whether these were expressed by lexical items or in some other way such as a gesture.

[16] Numbers in brackets refer to the number of controls that produced each form.

iv) Written Output

- **Written Picture Naming (PALPA 53) (Kay, Lesser, & Coltheart 1992)**

This task is included to provide information about participants' access to written language. In combination with tests such as Spoken Picture Naming, Spoken Word to Picture Matching and Pyramids & Palm Trees, this test also provides evidence about participants' access to lexical and semantic representations from pictures, which is relevant to interpretation of the results of the Picture-Word Verification task in experiment two.

There are forty items, each of which is a black and white line drawing of an object or animal. (The same items are used as in PALPA 53 Spoken Picture Naming to allow comparison). The participant is shown each picture in turn and asked to write its name. One mark is scored for each item correctly named. Interpretation of results also takes account of error patterns as evidence of levels of processing that might be impaired.

Normative data for 29 controls:

n = 40 mean = 39 SD = 1.33

- **Written Event Description** (adapted from Marshall, Pring & Chiat, (1993))

This task is included to provide information about participants' access to written language beyond the single word level. The task is the same as in Spoken Event Description, except that participants were asked to write a sentence describing what happened in the video clip. (These clips are items 25-32 of the Role Video Test). In four of the events the human participants are visible in addition to the instrument and/or theme (e.g. a man shoots a woman who falls to the ground). In the remaining four items only the theme and instrument of the event are visible (e.g. a peeler peeling a potato). As several of the aphasic participants were known to have severely restricted written output, they were instructed that they could draw pictures to supplement their writing in order to convey the message.

Data were analysed as in Spoken Event Description.

Assessment of sentence processing

- **TROG: Test for the Reception of Grammar (Bishop 1989)**

This task assesses the ability to understand a range of lexical and grammatical distinctions and is included to provide information on the aphasic participants' abilities to derive meaning from linguistic structure.

There are eighty items, organised into twenty blocks of four. Each block tests understanding of a specific type of grammatical contrast. Each item consists of a linguistic stimulus, together with an array of four pictures. In the standard presentation the stimulus is spoken aloud by the examiner. In addition to this auditory presentation, this test is administered here using written stimuli. The array consists of the target picture plus three distractor pictures. Distractors are both lexical and grammatical for blocks A-L, and grammatical only for blocks M-T. For each item the participant is required to select from the array of pictures the one that corresponds with the stimulus phrase or sentence. A block is passed if all four items on that block are responded to correctly. Blocks are sequenced in order of increasing difficulty, based on patterns of normal development in children).

Normative data is available for children between the ages of 4 years and 12 years 11 months. One hundred and fifty two children between the ages of 12;0 and 12;11 were tested, with 75% of them passing at least 17 blocks. Limited normative data is available for adults, and this suggests that a score of sixteen or more blocks passed is normal.

- **Sentence Semantic Anomaly Judgement (Woolf, unpublished)**

This task assesses the ability to process and integrate the core lexical-semantic representations within a sentence, and to recognise when the relations between these core elements indicate that a sentence is semantically and/or pragmatically anomalous. It is included to determine whether difficulties participants display in the Sentence Lexical Decision task in experiment one might be attributable to difficulties with making semantic judgements about sentences rather than to difficulties in auditory processing.

There are sixteen items, all syntactically permissible active non-reversible sentences (see Appendix 8). The examiner says each item in turn, and the participant is asked to judge whether the sentence makes 'normal good sense'. Eight of the sentences are plausible, while eight are anomalous. One mark is scored for each correct response.

Normative data on this task were obtained from the ten control participants who participated in the study, none of whom made any errors.

Summary

This chapter has outlined the procedures for recruiting participants, the selection criteria, and the assessments used in profiling of aphasic participants. In the next chapter a detailed profile of each aphasic participant will be presented, before the three experiments are reported in chapters four, five and six.

Chapter 3 Profiles of Aphasic Participants

Introduction

A range of language processing and related assessments was carried out with each aphasic participant. This provided an individual profile of impaired and preserved access to different levels of linguistic representation. Although all five of the aphasic participants demonstrated impairments in phoneme discrimination, many differences were found between them in their aphasia presentation. The individual profiles were used to assist with interpretation of patterns of performance on the experimental tests of auditory processing. All testing was carried out by the author, a qualified speech & language therapist who has extensive experience of assessing language processing in aphasic adults.

For each participant the profile includes:

- Background information
- Results of screening assessments of auditory processing

- Results of profiling assessments

    - Visual-semantic processing
    - Auditory input
    - Visual input
    - Spoken output
    - Written output

- Summary of assessment profile

Case details of the aphasic participants are summarised in Table 6. A table summarising the results of all the profiling assessments for each participant is provided at the end of this chapter.

Aphasic Particip ant	Sex	Age	Occupation (Pre-stroke)	Months post onset of aphasia	Stroke history
AL	M	62	Engineering production manager	15	Left hemisphere CVA following pulmonary embolism. Resulted in aphasia and dense right hemiparesis. Wheelchair user. Fatigues easily
JW	M	58	Car mechanic and graphic artist	22	Left hemisphere stroke. Resulted in aphasia, dyspraxia and dense right hemiparesis. Wheelchair user.
JWh	F	59	Personal Assistant	9	Left hemisphere stroke. Resulted in aphasia, dyspraxia and right hemiparesis mainly affecting arm/hand.
TDS	M	50	Police constable	11	Left middle cerebral artery CVA. Resulted in aphasia and mild right hemiparesis (almost completely resolved).
TVR	M	53	Distribution manager and Lorry driver	16	Left parietal CVA. Resulted in aphasia and right hemiparesis. Walks short distances with a stick.

Table 1. Summary of aphasic participants

Profile of AL

Background Information

AL, a 65 year-old man, had been aphasic for fifteen months prior to participation in the study. His aphasia was the result of a left hemisphere stroke following a pulmonary embolism. The stroke had also resulted in a dense right hemiplegia, requiring AL to use a wheelchair. Since his stroke he had also suffered from fatigue, which at times affected his ability to concentrate.

AL was living with his wife who was his main carer. He was a qualified draughtsman and engineering designer. Prior to his stroke he had been working as a production manager in an engineering company, managing a team of forty men. His wife reported that before his stroke AL had had a good standard of literacy and numeracy. He had been a keen reader of novels and newspapers (including the Daily Telegraph), wrote a personal diary and used a computer routinely.

Screening Assessments

Auditory Perception

Pure tone audiometry revealed that AL has a moderate high frequency hearing loss in his right ear, and normal hearing thresholds in his left ear at the frequencies tested.

Frequency Hz	Hearing Level dB (right ear)	Hearing Level dB (left ear)
1000	30	10
2000	30	20
4000	80	25

The auditory stimuli used in the experiments discussed in chapters four, five and six were presented free-field to both ears, with the loudspeaker adjusted to a comfortable listening level for each participant. Therefore AL's unilateral hearing loss would be expected to have little impact on his performance in those tests.

Nonword Phoneme Discrimination

AL scored 83/123 (68%) on the screening test of nonword phoneme discrimination. This score is outside the normal range (96-99%) and indicates a significant impairment of acoustic-phonetic processing. It was observed that AL appeared to be using silent repetition of the stimuli in order to make his judgements (based on observations of slow responses, concentrated facial expression, and side-to-side movements of head and eye-gaze as if weighing up two items). He showed a tendency to respond 'yes', with more correct responses to same pairs:

same pairs	52/62	(84%)
different pairs	31/61	(51%)

Auditory Lexical Decision

AL scored 121/158 (77%) on this test, which is below the normal range (93-99%). He showed a strong effect of lexicality, with errors consisting mainly of acceptance of nonwords. This may indicate that AL has reduced thresholds for lexical access or a positive response bias in this task.

words	75/80	94%
nonwords	46/78	59%

Profiling assessments

Visual-semantic processing

AL's performance on these tests falls around the boundary of the normal range.

On the **BORB Object Decision** test, he scored 28/32 which is just within the normal range. His errors included two false negatives (rejecting *deer* and *goat*), and two false positives (both involving unreal animals). His score of 47/52 on **Pyramids and Palmtrees** falls just below the normal range, suggesting a slight difficulty in processing the semantic/pragmatic relations between pictures. He made only one error on the **Role Video Test** (score 15/16), which involved the selection of a picture representing an event of a different nature from that observed (a sliced banana instead of the target of a mashed banana).

Taken together, these results may indicate that AL has a mild impairment of central semantic processing, or that he is not always able to attend carefully to visual stimuli. It is also possible that both semantic and visual processing are mildly impaired. Some support for this latter hypothesis can be found in the results of Spoken and Written Word-Picture Matching (see below). This is relevant to interpretation of AL's performance on the Picture-Word Verification task presented in chapter six, since this task involves the processing of pictures at a semantic level.

Auditory input

The results of these assessments, in conjunction with the screening assessments described above, reveal that AL has significant impairments of auditory processing at a number of levels of representation.

On **Auditory Rhyme Judgement** AL made nine errors on the thirty items tested. The test was discontinued since AL indicated that he wished to stop. Most of his errors were false positives (correct *Yes* responses 13/15, correct *No* responses 8/15), and were distributed across Spelling Pattern and Phonological Control sets:

	correct
Spelling Pattern Rhyme	7/9
Spelling Pattern Control	4/6
Phonological Rhyme	6/6
Phonological Control	4/9

Although AL's performance on this task is clearly impaired, it is difficult to be certain at which levels his processing was breaking down. He does not appear to be making use of spelling patterns to assist his judgements, which is unsurprising since his access to orthographic output is severely impaired (see below). It is unclear whether the large proportion of false positive responses was due to poor understanding of the task requirements, or to a specific difficulty in rhyme judgment together with a positive response bias.

On **Spoken Word-Picture Matching**, Al's performance (34/40 with a further three correct responses following self-correction) was below the normal range. His errors included two close semantic distractors, one of which was also visually related to the target (selecting *hoe* for *rake*). He made one visually related error (selecting *lightbulb* for *bell*), and this was the only item for which he requested repetition of the word before responding. His three self-corrections all involved close semantic/visual distractors. Although AL is usually able to access the correct semantic representations for the highly imageable nouns tested, his processing is impaired. As discussed in relation to the tests of visual-semantic processing, it appears likely that both semantic and visual processing are mildly impaired given his pattern of errors and self-corrections.

AL scored 27/36 on **Auditory Synonym Judgement** before this test was discontinued due to his fatigue. His errors were distributed across synonyms and control pairs, but show a clear effect of imageability. On the high imageability pairs he scored 15/17 (e.g. wrongly accepting *grave-blossom*), while on the low imageability pairs he scored only 12/19 (e.g. wrongly accepting *agreement-threat*). This is outside the normal range based on limited control data, and provides further support for the hypothesis that he has an impairment of central semantic processing.

The **TROG** revealed that AL's ability to process morphological and syntactic information in spoken input is severely impaired. He scored 33/64 with a further eight correct responses following repetition of the stimulus and/or self-correction.AL passed only five blocks,and the test was discontinued after sixteen blocks due to his frustration. The first two blocks (nouns and verbs) were passed without error, but AL made a number of self-corrections on the other three blocks that he passed (two element combinations, negatives and reversible actives). This indicates some degree of difficulty in processing these structures. He made errors on all the other syntactic relations tested, and showed an increased need for repetition of the stimuli involving spatial prepositions and complex sentences.

AL's ability to process semantic relations within sentences appears to be much stronger than his processing of syntactic relations. On **Sentence Semantic Anomaly Judgement** he scored 15/16. He requested repetition of two anomalous items (*'We watched a film on the radio'* and *'This house is built of cotton'*) before correctly rejecting them.

Visual input

AL's reading abilities are severely impaired as a result of his stroke. He has difficulty processing written language at a number of levels of representation, including lexical, semantic and syntactic.

AL does not appear to have difficulty in the visual perception of letters, (despite his possible visuo-perceptual difficulties related to pictures). On the **Letter Discrimination: Mirror Reversal** test he scored 35/36, which is within the normal range. However, his ability to recognise written words is very compromised, with performance on **Visual Lexical Decision** (83/120) well below normal. This score was significantly above a chance level of 50% correct (ANOVA p <.001**). His errors are randomly distributed across sets, showing no effect of lexicality, word frequency or imageability.

Lexicality:	words	41/60	nonwords	42/60
Frequency:	High	21/30	Low	20/30
Imageability:	High	18/30	Low	23/30

AL also has considerable difficulty accessing semantic representations from written words. On **Written Word-Picture Matching** he scored 26/40, which is well below the normal range and also significantly worse than his performance on the spoken version of this test. His errors included seven close semantic distractors, of which three were also visually related to the target (e.g. selecting *spear* for *dart*). One error involved a distant semantic distractor (*mirror* for *comb*), and for four items he chose the visual distractor (e.g. *wheel* for *cobweb*). He also made four unrelated errors (e.g. selecting *glove* for *candle*). These results appear to support the hypothesis suggested earlier that AL has impairments of both central semantic processing and of visual perception of pictures. The fact that AL's performance on this task was considerably poorer than on the spoken version of this test, as well as the fact that he selected the unrelated foil on four occasions, suggests that some of his errors may have arisen from his difficulty in recognising written words (as shown by lexical decision), and/or that he has difficulty accessing the semantic system from written word-forms.

On **Written Synonym Judgement** AL scored below the normal range (37/60), confirming that his ability to access meaning from written words is severely impaired. This score is not significantly above a chance level of 50% correct (ANOVA p =.190). AL tended to respond *yes* more often:

Correct yes responses	24/30
Correct no responses	13/30

He scored 21/30 on high imageability pairs and 16/30 on low imageability pairs, but there was no significant effect of imageability (chi square p =.184).

AL's performance on the written version of the **TROG** was poorer than on the auditory version of the same test. He scored 29/64, with one further correct response following a self-correction (to the first item 'shoe'). He passed only two blocks, those involving nouns and two-element combinations, and the test was discontinued after block sixteen as AL showed signs of frustration. He made errors on verbs and adjectives, as well as on all the morphological and syntactic relations tested.

Spoken output

AL's spoken output is severely impaired. In conversation, his speech consists of a combination of some recognisable words and phrases, together with well intonated but unintelligible strings of syllables. These strings often appear to be neologistic, although low volume of speech combined with imprecise articulation of consonants often makes his speech very difficult for the listener to discriminate. At times AL is able to produce clear and appropriate words and phrases, although articulatory difficulties mean that these are sometimes only recognisable within a clear context. His output often contains the words 'yes' and 'no', but these are produced very unreliably. These words are frequently accompanied by nodding or shaking his head, but this is equally unreliable. When prompted, AL is able to produce reliable yes/no responses by pointing to a choice of the two words written down. He also produces numbers, appropriate social phrases (such as 'bye' and 'oh crikey'), and some specific and appropriate lexical items. His speech is often accompanied by gestures, although these tend to be very imprecise and difficult to interpret without a very clear context. His monitoring of his own output appears to be impaired, as he does not usually attempt to self-correct and appears to expect his listener to have understood him most of the time.

On **Spoken Picture Naming** AL scored 0/40. He produced a spoken response to each item, each of which was a nonword. None of these bore any phonological similarity to the target, and often consisted of strings of syllables. For instance, he named *horse* as [pœ] then [pɸœʔʒəˈspeɪs], *screw* as [ˈɛʔsələ], and *cow* as [ɛsɪʔˈɛbβɯ]. Many of his responses were spoken at very low volume and imprecisely articulated.

AL produced a combination of non-iconic gestures and speech in response to each item in **Spoken Event Description**. Spoken responses were mainly unintelligible and imprecisely articulated. Responses to three items included a recognisable word *(bang),* phrase *(first one),* or counting series *(one, two three, four, five)*, but with the exception of the first example these conveyed little relevant information. Gestures were imprecise, but conveyed some information about the participants, nature, location and/or directionality of each event. Most responses lacked at least one of the obligatory verb arguments expressed by the controls. For instance, in response to the item in which a man hits a woman, AL described the nature of the event by saying [ɸwʊʃ] then *'bang'* (it is unclear whether this was used as a verb or noun).

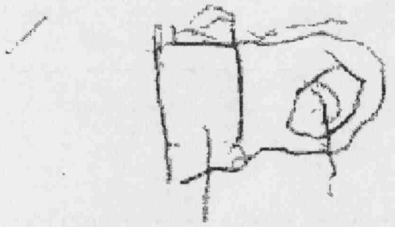
He conveyed optional aspects of the event by pointing to his nose, but omitted any reference to the actor participant. For the item in which a man flicks water at a woman, AL indicated that there were two participants by gesturing towards two points in space, and conveyed the nature of the event by holding his left hand in front of his chest and making repeated flicking movements away from himself. He did not convey the theme (the water), perhaps because this would be difficult to express through gesture. The results of this assessment confirm that AL has little functional spoken output, but that he is able to communicate some information about events using gesture.

Written output

AL has no functional access to written output. He is able to copy words accurately when the target is in view, but cannot copy a word from memory immediately after the target is covered up. He was unable to produce any response to **Written Picture Naming** even with auditory cues, and was unable to complete written words when given the first few letters. The test was abandoned after the first few items.

AL's responses in Written Event Description were difficult to interpret. He produced a line drawing for each item, three of which included some marks that may have been attempts to write letters. Neither the drawings, nor the letters if that is what they were, were recognisable. For instance, for the item in which a woman closes a suitcase, he produced:

while for the item in which a man gives flowers to a woman, he produced:



It was not possible to analyse the nature of the information conveyed by AL to describe these events, but his performance on this task confirmed that his written output is severely impaired.

Summary of AL's assessment profile

AL presents with impaired language processing in all modalities. He appears to have a mild central semantic processing impairment resulting in semantic errors on a range of input tasks. In auditory processing he also has difficulties with phoneme discrimination, word recognition, and access to word meanings. His ability to process syntactic relations in spoken sentences is very impaired, but he has relatively preserved abilities in processing semantic relations in spoken sentences. In visual processing he may have a mild deficit in processing pictures. He is able to recognise letter-forms, but has great difficulty accessing lexical representations from written words. Access to the meanings of written words is more impaired than access to the meanings of spoken words, and the ability to understand syntactic relations in written sentences is severely compromised. AL's spoken output consists of some recognisable (though imprecisely articulated) words and phrases, combined with strings of unintelligible syllables. He also produces some gesture, although this is usually recognisable only in a very restricted context. AL has no functional access to writing.

Profile of JW

Background Information

JW, a 58 year old male, was aphasic as a result of a left hemisphere stroke twenty-two months before participation in this study. The stroke had also resulted in a dense right hemiplegia affecting upper and lower limbs (and requiring him to use a wheelchair), and a mild right sided facial paresis. He had been diagnosed by his referring speech and language therapist as having dyspraxia of an unspecified type.

JW and his wife both reported that he had had a good level of literacy prior to his stroke. He had enjoyed reading novels, and would often read for several hours at a stretch. JW also reported previously effective writing skills. Prior to his stroke JW had been working as both a graphic artist and a car mechanic, but had not returned to work since his stroke. He was living with his wife who was his main carer.

Screening Assessments

Auditory Perception

Pure tone audiometry revealed a bilateral high frequency hearing loss. JW had been unaware that he had a hearing loss, and did not report any functional difficulties arising from it.

Frequency Hz	Hearing Level dB (right ear)	Hearing Level dB (left ear)
1000	25	30
2000	25	35
4000	65	80

This profile falls within the acceptance criteria for participation in the study, since JW's average hearing level in his better ear is 36 dB. However, the loss of acuity in the higher frequency region would predict some loss of sensitivity to phoneme distinctions that are predominantly differentiated at high frequencies, such as place distinctions among fricatives. Perception of distinctions of voice onset time, manner and place (excepting fricatives) should be largely unaffected by JW's hearing loss. This prediction is in keeping with the finding of Tyler (1992 p.72), who showed that hearing impaired controls made far more errors on place contrasts than normally hearing controls, but showed only a small increase in error rate on voicing and vowel contrasts. JW's hearing loss was taken into consideration in analysis of his performance on assessments of auditory processing.

Nonword Phoneme Discrimination

JW scored 87/127 (66%) on this test, which is below the normal range (96-99%) and indicates a severe impairment of the ability to perceive phoneme contrasts. Almost all of his errors involved different pairs:

same pairs	63/64	(98%)
different pairs	24/63	(38%)

It was noted during testing that JW had responded correctly to all of the practice items (confirming that he understood what was required in the task). It is possible that he was assisted during the practice items by lip reading information since the practice items were presented live. However, his pattern of impairment cannot be adequately accounted for on the basis of his high frequency hearing loss, because many of the distinctions that he failed to perceive are carried by acoustic differences in the lower frequency regions, and/or are distinguished by other differences such as vowel duration and other temporal contrasts.

Auditory Lexical Decision

JW scored 134/155 (87%) on this test. His performance on this task is below the normal range (93-99%), indicating an impairment of the ability to access lexical representations from auditory input. His errors were mainly acceptance of nonwords rather than rejection of words.

words	73/77	(95%)
nonwords	61/78	(78%)

During testing it was observed on a number of occasions that JW correctly rejected a nonword, then a moment later indicated to the examiner (using gesture, facial expression and intonated vocalisation) that he had just 'recognised' the nonword and believed he had given an incorrect response. A similar pattern, in which he correctly accepted a word and then indicated that he had made a mistake, was not observed.

Profiling assessments

Visual-semantic processing

JW's performance on the **BORB Object Decision** test (31/32) was within the normal range and indicates that he is able to access stored visual representations. He also scored within the normal range on **Pyramids and Palmtrees** (49/52), suggesting that he is able to process semantic and pragmatic relations between pictures. He made no errors on the **Role Video Test** (16/16)[23], indicating that he is able to make accurate predictions about the likely outcomes of events, and the roles played by participants in those events.

[23] Presentation of this task to JW deviated slightly from the assessment protocol, in that items17-32 from the Role Video were used instead of items 1-16. Items 1-8 of the Role Video were instead presented to JW for Spoken Event Description, and items 9-16 for Written Event Description. This alteration in the order of presentation occurred in error, but is not considered likely to have affected JW's performance on these tasks.

Auditory input

The screening tests revealed that JW is severely impaired in phoneme discrimination, and impaired in access to lexical representations from spoken words. He also has difficulty in accessing semantic representations from auditory input, even for high imageability nouns. On **Spoken Word-Picture Matching** he scored 32/40 with two further correct responses following self-correction, which is below the normal range. Errors included six close semantic distractors, of which four were also visually related to the target, and JW also self corrected one close and one distant semantic error. This suggests that he is able to access the appropriate semantic field from spoken words, but that he is sometimes unable to access the precise target representation within that field.

Performance on **Auditory Synonym Judgements** (23/60) was below the normal range, and not significantly above a chance level of 50% correct (ANOVA p =.795). There was no effect of imageability:

High Imageability	11/30
Low Imageability	12/30

It cannot be ruled out that JW may not have understood what was required of him on this task. However, his performance on the written version of the task (see below) was well above chance suggesting that he did understand what was required on that presentation. These results seem to confirm that he has considerable difficulty in accessing precise semantic representations from spoken words. However, the results of this assessment may suggest a more severe impairment than was revealed by performance on Spoken Word-Picture Matching, since JW performs at no more than a chance level even on the highly imageable items.

It is possible that JW's access to semantic representations was assisted during the word-picture matching task by the presence of the pictures, which immediately narrow down the possible cohort of semantic targets to five. In contrast, the auditory synonym judgement places less constraint on the possible cohort of semantic representations, thus placing a greater processing load on access and selection mechanisms. An alternative explanation is that JW's poorer performance on auditory synonym judgement results from a difficulty with some other aspect of the task demands, such as the requirement to hold and compare two words in working memory. These factors will be considered in relation to his performance on experimental tests of auditory processing.

Despite JW's difficulties in processing auditory input at phonemic, lexical and semantic levels of representation, he has relatively preserved processing of syntactic structures in spoken sentences. On the auditory presentation of the **TROG** scored 42/52 on the main test, with a further seven correct responses following repetition of the stimulus and/or self-correction. During the preliminary vocabulary check JW had requested repetition of four items. He correctly identified 40/48 vocabulary items, with a further four correct responses following repetition of the stimulus and one following a self-correction. His errors were made on the final block of vocabulary testing, and all involved selecting a picture from the same semantic category (either size or colour) as the target:

big → *tall*   *tall* → *big*   *red* → *yellow*

Semantic errors on content words did not however contribute to JW's errors on the main test. The blocks that he failed were those that tested reversible sentences, personal pronouns, and the prepositions in/on, and he was able to process plural noun inflections despite his high frequency hearing loss. His requests for repetition of a number of items suggest he was aware that he was having difficulty processing some of the structures. Overall the results of this test indicate that JW has difficulty in processing some functors, as well as some difficulty in thematic role assignment (at least in reversible sentences).

JW's performance on **Sentence Semantic Anomaly Judgement** (15/16 with a further correct response following repetition of the stimulus) indicates that he is able to process and integrate the core lexical-semantic representations within a sentence, and to recognise when a sentence is semantically and/or pragmatically anomalous.

Visual input

JW made some errors on **Letter Discrimination: Mirror Reversal** (34/36), both acceptance of reversed letters, and he also self corrected a further error of the same type. This suggests that JW is able to recognise letters with correct orientation, but that his criteria for recognition are underspecified resulting in occasional acceptance of reversed letter-forms.

On **Visual Lexical Decision** JW scored 103/120. He showed a strong effect of lexicality, with most of his errors involving acceptance of nonwords:

Nonwords	46/60
Words	57/60

JW's performance on the word items is comparable to control subjects, and shows no effect of either word frequency or imageability.

High Frequency	29/30	Low Frequency	28/30
High Imageablity	29/30	Low Imageability	28/30

This suggests that he is able to recognise written words, but that his criteria for lexical access may be underspecified resulting in his erroneous 'recognition' of some nonwords, or that he has a positive response bias on this task.

JW's access to semantic representations from written words is impaired. On **Written Word-Picture Matching** he scored 31/40 with a further two correct responses following self-correction. This is below the normal range, and errors included six close and one distant semantic distractor. Only one of the close semantic errors was visually related to the target. JW self corrected a further two close semantic errors. This suggests that he is usually able to access the appropriate semantic field from written words, at least for highly imageable nouns, but that he is sometimes unable to access the precise target representation within a semantic field. This notion is supported by JW's performance on **Written Synonym Judgement** where he scored below the normal range (49/60). He showed a strong effect of imageability, indicating difficulty in accessing the semantic representations of the low imageability items.

High Imageability	28/30
Low Imageability	21/30

On the written presentation of the **TROG,** JW scored 43/64, with one further correct response following a self-correction. The blocks that he passed included nouns and adjectives, but not verbs. He also passed the blocks testing two- and three-element combinations, and verb negation. He was able to process plural inflections but not plural pronouns, and failed to comprehend any of the other syntactic structures tested.

Spoken output

JW's access to spoken output is severely restricted. In conversation his speech consists almost entirely of the words 'yes', 'aye' and 'no', which are not always used reliably. He is also able to produce some social phrases (such as 'oh', 'what?' and 'bye'). Using this very restricted vocabulary, he varies his intonation patterns in order to fulfil a range of conversational roles. He is able to supplement his speech with gestures and elaborate pantomimes, though these are often only recognisable in context. He can also draw detailed pictures to communicate, although he doesn't often do this spontaneously.

On **Nonword Reading** JW was unable to read any of the items correctly, and the test was discontinued after seven items. This task had been presented immediately after the non-standard procedure of using the same nonword items in a written copying task, since previous observations had indicated that JW was unlikely to achieve any success in a straightforward nonword reading task. He was therefore asked to copy the items before attempting to read them aloud to allow for the possibility that activation of phonological representations might be facilitated by cross-modality priming. Although he was able to copy all the items accurately, JW was unable to read any of the three letter items aloud despite making two-to-four attempts to say each item. None of his responses shared any phonemes with the target indicated by the spelling of the nonword, and many of his responses appeared to be perseverative. JW also attempted to read one four letter item aloud, to which his response contained the correct initial consonant, an incorrect vowel and lacked an obligatory final consonant. The test was discontinued at this point.

It was already clear from observation of JW's attempts at spoken output (both in conversation and during formal assessment tasks) that he would perform at or near to the floor of **Spoken Picture Naming.** The task instructions were therefore modified to increase the likelihood of his being able to give some response to the items. JW was asked to convey something about the picture using a gesture before attempting to name it, to see if he was able to cue his own spoken output by first producing a semantically related gesture. JW responded to all items by producing an appropriate gesture, but correctly named only 2/40 items. He attempted a spoken response to eight items. In five of these cases his responses were phonologically unrelated nonwords, with some perseveration of previous responses. For instance, he said [tuːp] in response to both the picture of a fork and the picture of a loaf of bread. JW attempted unsuccessfully to correct these responses, indicating that he was able to monitor his output phonologically. He made one semantic error in response to *star* for which he said *'bright'*. His only correct responses were for *dog* → *'dog'* and for *yacht* → *'boat'*.

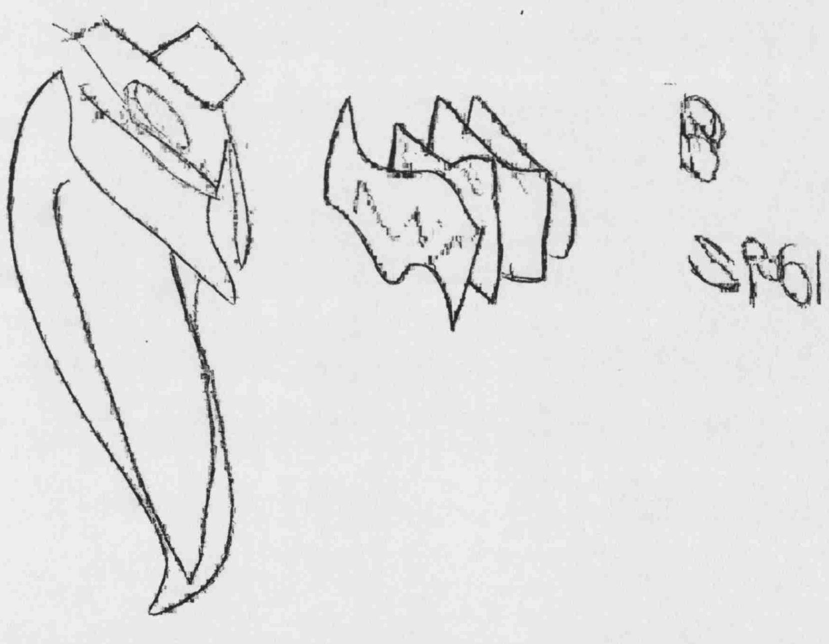
JW's gestures clearly expressed semantic attributes of the pictures such as the size, shape and functional use. Often these features were sequenced appropriately into elaborate pantomimes in which gestures were combined with facial expressions, intonated vocalisations and whole body movements in order to convey a semantically rich message. For instance, for the picture of a *lemon,* he first traced the shape of a lemon on the table with his finger, then mimed picking it up with his fingers and putting it in his mouth, and finally screwed up his face as if he had eaten something sour or distasteful. Such gestures and pantomimes are typical of his spontaneous output in conversation, and suggest that he is able to generate semantically rich representations even when unable to access verbal representations to express them.

On **Spoken Event Description** JW attempted a spoken response to six of the eight items. In all of these attempts his productions were a series of up to four monosyllables which appeared to have no structural similarity to any likely target words. For instance, for the item in which a woman receives flowers from a man he said: [sː] [ʃtəʊ] [fɔː] [ʃɛf]. JW expressed non-verbally that his spoken responses were wrong, indicating that he has some ability to monitor his spoken output. JW also responded to each item by producing appropriate gestures to convey the participants in the event. For instance, for two items with a female participant, he made a gesture alongside his legs to indicate the shape of a skirt. He often produced an elaborate pantomime to convey the nature of the event itself. For instance, for the event in which a man throws a ball to a woman, JW made a hand position as if holding a small ball, gestured throwing it, paused, and then pretended to catch the ball. JW's performance on this task suggests that he is able to generate appropriate representations at the message level (as evidenced by his nonverbal responses), but that he has a severe impairment of the ability to access linguistic representations to convey messages. This finding is in keeping with observations of JW's spontaneous communication.

Written output

JW has very little access to orthographic representations. On **Written Picture Naming** he scored 1/40, and only produced a response to four of the items. These responses may have been perseverative as the first two were the letter '*c*' in response to *comb* and *bear*. He later expanded one of these to '*cow*' in response to *cow*, and responded '*a c*' to *arrow*. JW was unable to complete any items correctly when provided with the initial letter or letters, together with underlinings to indicate how many more letters were required. The test was discontinued after item 13.

JW attempted a written response to all eight items on **Written Event Description**. These each consisted of a single string of two to four letters for which the target was not certain, although at least three responses shared some spelling similarity with a word that would be an appropriate target. In different cases this may have been a verb (*SPOT* for the item in which a man shoots a woman), a theme (*Pra* for the item in which a plank of wood is sawn), or a recipient (*BULL* for the item in which a bucket is filled with water). He indicated that these written forms were incorrect, but was unable to amend them. For seven items JW chose to draw his response prior to attempting to write. Due to poor execution using his non-preferred hand JW's pictures would be difficult to recognise out of context. His drawings represented the themes of three events, and the instruments of three events. The participants who were visible in the video were drawn for three items, but omitted from four others. For instance, JW drew a camera and several banknotes as themes of the event in which a woman sells a camera to a man, but did not draw the participants or indicate the directionality of the event:



The results of this assessment confirm that JW has very little access to written output, but is able to convey some relevant information using non-verbal means.

Summary of JW's assessment profile

JW is severely aphasic, and his auditory processing is characterised by severely impaired phoneme discrimination. He has impaired word recognition and impaired access to semantic representations from both spoken and written words. He is able to comprehend a range of syntactic structures in spoken sentences when able to hear the stimulus more than once, as well as to process semantic relations within spoken sentences, but comprehension of syntactic structures in written sentences is very limited. He has almost no access to spoken or written output, but is able to convey semantically rich messages through a combination of intonation, gesture, pantomime and drawing.

Profile of JWh

Background Information

JWh, a 59 year-old woman, had been aphasic since a left hemisphere stroke ten months before participation in the study, which had also resulted in a right hemiparesis mainly affecting her arm and hand. Her referring speech and language therapist reported that her speech was affected by dyspraxia. Prior to her stroke JWh had worked as a Personal Assistant, indicating a good standard of literacy, but had been unable to return to work since. She was living with her husband and one of their adult daughters.

Unfortunately JWh suffered a second minor stroke during the period of her participation in the study. This occurred three weeks after completion of the screening and language profiling assessments, and just before experimental testing was due to commence. She was admitted to hospital where she was reassessed by the referring speech and language therapist who had worked with her since the time of her first stroke, and so was familiar with the presentation of her aphasia. This therapist reported that the second stroke had had no effect on JWh's language or communication. JWh and her husband also reported a month later that the second stroke had had no effect, except that she had become very anxious and was often tearful.

Nevertheless JWh expressed her desire to continue participation in the study. She was therefore visited two months after the second stroke to discuss her capacity to participate in further testing. Two of the language profiling assessments (Auditory Synonym Judgement and Visual Lexical Decision) were repeated to ascertain whether JWh's aphasia had changed since the second stroke. The results of both of these tests (detailed below), and observation of her communication, confirmed that there had been no change. It was agreed that JWh would remain in the study and proceed onto the experiments.

Screening Assessments

Auditory Perception

Pure tone audiometry revealed a somewhat unusual mild bilateral low frequency hearing loss, but normal thresholds within the middle to high frequency range.

Frequency Hz	**Hearing Level dB (right ear)**	**Hearing Level dB (left ear)**
1000	35	45
2000	20	10
4000	15	5

Nonword Minimal Pair Discrimination

JWh achieved an overall score of 110 / 128 (86%). This was outside the normal range (96-99%) and indicated an impairment of phoneme discrimination. Almost all of her errors were on the different pairs.

same pairs	63/64	98%
different pairs	47/64	73%

Auditory Lexical Decision

JWh scored 151/160 (94%) on this test. This score falls within the normal range (93-99%), and revealed no effect of lexicality.

words	76/80	95%
nonwords	75/80	94%

Profiling assessments

Visual-semantic processing

JWh made no errors on the **BORB Object Decision** test (32/32), indicating that she is able to process and recognise pictures. On **Pyramids and Palmtrees** she scored 47/52, which is just below the normal range and may indicate a slight impairment of central semantic processing. Approximately two thirds of the way through this test JWh expressed uncertainty about the nature of the task. However, her responses up to that point had suggested that she was making judgements based on the appropriate semantic and/or pragmatic associations between the pictures. On the **Role Video Test** JWh scored 16/16, indicating that she is able to make accurate predictions about the likely outcomes of events, and the roles played by participants in those events.

Auditory input

From the screening tests it can be seen that JWh has impaired phoneme discrimination, but despite this she has good access to lexical representations from spoken words. On **Spoken Word-Picture Matching** she scored 38/40, which is within the normal range. Both of her errors were close semantic distractors, suggesting that JWh is able to access the appropriate semantic field for highly imageable nouns, and is usually able to process fine semantic distinctions between them. On **Auditory Synonym Judgements** she scored 47/60 with a further four correct responses following repetition of the stimulus,which is below the normal range. All of her errors were false negatives, and JWh shows a trend towards an effect of imageability on her ability to judge semantic similarity (chi square p =.071).

High Imageability 28/30
Low Imageability 23/30

Together, these tests suggest that in addition to her impairment of phoneme discrimination, JWh has a mild impairment of access to the semantic representations of words from auditory input.

JWh scored 38/52 on the **TROG**, with a further eight correct responses following repetition of the stimulus and one self-correction. She passed nine out of the thirteen blocks she attempted She passed all the items in the vocabulary check, confirming that she was able to comprehend the lexical items used in the main test. She was also able to comprehend singular/plural personal pronouns, singular/plural noun inflection, and verb negation. She was unable to process the active or passive reversible sentences, and also failed on the comparative sentences perhaps due to the reversible nature of these constructions. Although she responded correctly for the block testing prepositions *in* and *on,* she required repetition of three of the four items and was slow to respond, indicating some difficulty. Blocks testing more complex syntactic structures were not administered as JWh was expressing frustration with her performance on this test.

JWh made no errors on **Sentence Semantic Anomaly Judgement** (16/16), indicating that she is able to process and integrate the core lexical-semantic representations within a sentence, and recognise when a sentence is semantically and/or pragmatically anomalous. However, it was noted that she requested repetition of two items before responding, indicating some difficulty in processing the input.

Visual input

JWh is able to recognise written letter-forms, as shown by her score of 36/36 on **Letter Discrimination: Mirror Reversal.** Her access to lexical representations from written words is impaired, since on **Visual Lexical Decision** she scored 109/120 which is more than three Standard Deviations below the control mean score. She made slightly more errors on words (53/60) than nonwords (56/60), and showed a slight effect of word frequency (chi square $p = .038^*$), but not of imageability:

High Frequency	30/30	Low Frequency	26.5/30
High Imageablity	29/30	Low Imageability	27.5/30

(Half a mark is scored when the participant is unable to make a decision).

On **Written Word-Picture Matching** she scored 39/40, which is within the normal range. Although JWh made only one error on this task (involving a close semantic distractor), she made a number of self-corrections (on three occasions initially selecting the close semantic distractor, and on one occasion the distant semantic distractor). She also hesitated at length before responding on almost a quarter of the items. JWh's score on **Written Synonym Judgement** (58/60) was within the normal range. This suggests that she is able to access the meanings of written words reliably, with both of her errors on low imageability pairs. However, it was observed that on about one fifth of items she suggested through gesture and facial expression that she was just guessing. Her uncertainty on both of these tasks may indicate that she has a slight impairment in accessing semantic information from written words that is not severe enough to reduce significantly her accuracy of response, but reduces her confidence in her judgements.

JWh's difficulty in processing written information is more apparent for syntactic structures. On the written presentation of the **TROG** she scored 35/56, with a further three correct responses following self-corrections. She passed only four blocks out of the fourteen that she attempted, which is poorer than her performance on the spoken version. The blocks that she passed were nouns, adjectives, two element combinations and negatives. She failed the lexical block testing verbs, as well as all other morphological and syntactic relations tested. The test was discontinued as JWh was becoming distressed, and had been unable to select a picture for five of the last six items presented.

Spoken output

In conversation, JWh's speech is characterised by appropriate use of social phrases together with limited production of noun phrases, which are often the names of familiar people and places. She often says "I can't..." when unable to express herself. She is sometimes able to supplement her speech with gestures, although these can be unclear due to limb dyspraxia. She can also sometimes write words that she cannot say, though this also tends to be restricted to familiar names and some nouns.

On **Nonword Reading** JWh scored 1/24. She attempted to read aloud 22/24 items (both of the items to which she gave no response were three letter strings), but was only able to read one of these correctly. She was aware that her responses were incorrect, but did not attempt to modify them. She tended to lexicalise items since half of her responses constituted real words, most of which were structurally related to the stimulus (e.g. *shid* ⇒ 'shed'). One response may have indicated a semantic error (*soaf* ⇒ 'bed' perhaps via *sofa*). She also perseverated on the responses 'smoke' and 'soap' for most of the five and six letter strings (perhaps related to fatigue as these longer strings are presented after the three and four letter strings). JWh is unable effectively to use grapheme-to-phoneme conversion rules in order to read nonwords, but appears to attempt to compensate for this by using a lexical route to reading aloud.

Performance was better on **Spoken Picture Naming** (19/40) where JWh gave a spoken response to 37/40 items. Eight of her errors were close approximations of the target, distorted at the phonetic/articulatory level (e.g. *knife* ⇒ [nalp], *glove* ⇒ [kçv]). In these responses it is clear that she had accessed the correct semantic and lexical targets, but had difficulty in producing them probably due to dyspraxia. A further seven responses were clearly semantic errors (some of them also distorted), such as *fish* ⇒ 'swim', *fork* ⇒ 'spoon' and *bread* ⇒ 'slice'. On a number of occasions JWh used gesture or finger-writing to try to cue her response; these strategies were successful on about half the occasions they were used.

JWh's responses on **Spoken Event Description** were similar to her conversational speech, although she was more successful at producing specific lexical items (perhaps strongly cued by the visual images on the video). She was usually able to refer to the human participants and the theme of the event, but produced very few verbs. She was sometimes able to convey the nature of the event using a gesture. For instance her response to the item in which a woman punches a man was: *"A girl...no no...well...well...a girl and a boy...fist...bang"* combined with a gesture of punching, while for the item in which an apple is sliced with a knife she said: *"Ooh no...oh...apple...pfuh...I can't imagine...I...ooh no...apple...no, I can't, God...apple."*

Written output

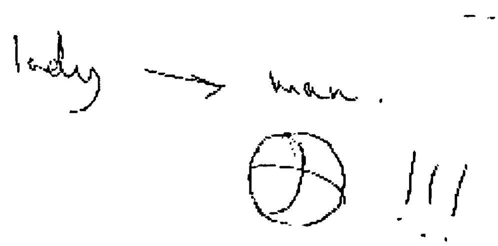
JWh is able to produce some writing to assist her when she is unable to say words. Her access to orthographic representations from semantics appears generally to be 'all or nothing', in that she either produces no response or the correctly spelled target.

On **Written Picture Naming** she scored 10/40. She made no response to twenty-six of the items. When she did attempt a written response to a picture, JWh generally produced the correctly spelled target, rapidly and in cursive script. Only four of her responses were incorrect. These errors were:

Swan	⇒	s
Scissors	⇒	scirr (crossed out) scif scissor
Watch	⇒	water (possibly a perseveration) wat
Yacht	⇒	yactley

In each of these cases it appeared that she was aiming for the correct lexical target, but was only able to retrieve a partial representation of the orthographic form. When asked about her no-responses, JWh conveyed that she was unable to access any representation of the written name. After the test, the author attempted to cue responses to three of the items to which JWh had given no response by providing the initial letter/s. She was able to complete bear from b___ , and glove from gl____. She wrote 'belf' in response to the written cue be___ for belt, but then corrected the spelling herself.

JWh's responses to **Written Event Description** were made up of written words augmented with pictures and arrows. The human participants in all items where they were visible on the video were expressed by writing the words *man* and *lady*, and the theme of each event was represented mainly through pictures. The verb was absent from all responses, except the item in which a potato is peeled for which JWh wrote *cut*. She was able to express the directionality of several events, despite producing no verb, by drawing arrows between the words she had written. For instance, she conveyed the item in which a woman throws a ball to a man by writing *lady* (the actor) and *man* (the recipient), and drawing the ball (the theme) beneath the recipient. There was no verb, but the directionality of the event was expressed by an arrow pointing from the actor to the recipient:



Summary of JWh's assessment profile

JWh presents with an impairment of phoneme discrimination. She has relatively well preserved access to lexical and semantic representations from both spoken and written words, although she lacks confidence in her judgements suggesting a slight processing impairment. She has difficulty comprehending syntactic structures particularly when these are presented in written form, but is able to process semantic relations within spoken sentences. She has very restricted spoken and written output, and mainly produces familiar names and appropriate nouns. She is able to augment these with gestures, drawings and arrows in order to convey rich representations at the message level.

Profile of TDS

Background Information

TDS, a 50 year-old man, had been aphasic since a left middle cerebral artery stroke twelve months prior to participation in this study. The stroke had initially resulted in a right hemiparesis, from which he had made an almost complete recovery. He had no other relevant medical history and was in good health.

TDS was working full time as a police officer prior to his stroke. He had since returned to work part time, but was only permitted to carry out very restricted duties because of his aphasia. This was a source of enormous frustration to TDS who felt he was capable of a much more responsible position. He was living with his wife and teenage daughter.

TDS was bilingual. He had spent his childhood in a multilingual community in Goa, India. English was his first language, and both he and his wife reported that he had been highly articulate in spoken and written English prior to his stroke. From birth TDS had acquired both English and Portuguese. He had spoken Portuguese only with his parents, and English with almost all other people in his family and community. He had attended only English speaking schools. He had also acquired some Marathi (which was spoken by some of his community) from the age of about five, and Punjabi from the age of seventeen, though he was never proficient in these languages.

Screening Assessments

Auditory Perception

Pure tone audiometry revealed that TDS had normal hearing thresholds at the frequencies tested.

Frequency Hz	Hearing Level dB (right ear)	Hearing Level dB (left ear)
1000	5	5
2000	10	10
4000	5	10

Nonword Phoneme Discrimination

TDS scored 99 /125 (79%) on the screening test of nonword phoneme discrimination. This is below the normal range of performance (96-99%) and indicates an impairment of acoustic-phonetic processing. His errors mainly involved responding 'same' to different pairs:

Same Pairs	58/61	(95%)
Different Pairs	41/64	(64%)

Auditory Lexical Decision

TDS scored 130/159 (82%) on the screening test of auditory lexical decision. This is below the normal range (93-99%) and indicates an impairment of lexical access from spoken input. He showed a strong effect of lexicality, with most of his errors involving acceptance of nonwords.

words	78/80	(98%)
nonwords	52/79	(66%)

Profiling Assessments

TDS was often keen to discuss his performance on these assessments, and was able to express clear opinions as to the nature of his language processing difficulties. A number of his comments are reported here alongside his test results, since these provided some valuable insights.

Visual semantic system

TDS's performance on both the **BORB Object Decision** (31/32) and **Pyramids and Palmtrees** (52/52) tests were well within the normal range. Together, these indicate that he is able to access stored visual representations in order to recognise pictures, as well as to process a range of semantic and pragmatic relations between pictures.

Performance on the **Role Video Test** (16/16) indicates that TDS is able to understand the roles played by participants in events, and can make accurate predictions about the likely outcomes of events.

Auditory Input

TDS has difficulty with auditory processing at phonemic and lexical levels, as shown by the screening tests. Further evidence that he has difficulty processing phonological information comes from his performance on **Auditory Rhyme Judgement**. He scored 41/60, with a further five correct responses after repetition of the stimulus. This indicates a difficulty in comparing the phonological forms of two words, with errors distributed across the sets of items:

Spelling Pattern Rhyme	10/15
Spelling Pattern Control	10/15
Phonological Rhyme	12/15
Phonological Control	14/15

TDS reported after the test that on some items (e.g. *tint-pint, hush-bush*) he had thought they rhymed due to their similar spelling patterns. While this might explain his greater accuracy on phonological controls than on spelling pattern controls, his errors on spelling pattern rhymes reveal that he does not consistently make use of the spelling pattern. This is unsurprising, since he has considerable difficulty in accessing orthographic representations. TDS also commented that he had found many items easy to judge (e.g. *king-sing*) because he found it easy to access their meanings. With some other items (e.g. *leaf-sheaf*) he was less certain of the semantics and felt that this had interfered with his ability to 'hear' the whole word

TDS's access to semantic representations from spoken words was tested through **Spoken Word-Picture Matching**, where he scored 36/40 with correct responses to the remaining four items following repetition of the stimulus. Although he made no incorrect responses, there were indications that he was having some difficulty in processing the input. It was observed that TDS expressed considerable uncertainty about two items (and asked to return to them for clarification at the end of the assessment), even though he had made the correct selection. In both of these items he was unsure whether to select the target or a distractor that was both semantically and visually related to the target (*lobster/crab, nail/screw*). TDS also requested repetition of four items before making his selection. Three of these items had close semantic distractors that are also visually similar to the target (e.g. *stool/table*). TDS explained his difficulties with these items by drawing pictures of a ship and a sailing boat. He conveyed that, although he knew exactly what both were, he might not be sure which was being referred to when he heard the name of one of them.

TDS's overall score on **Auditory Synonym Judgement** falls below the normal range based on limited control data (52/60 with repetitions allowed). His pattern of performance provides further evidence of a mild difficulty in accessing semantic representations from auditory input. TDS made more errors on low imageability pairs, although there was no significant effect of imageability overall (chi square p =.129):

High Imageability 28/30
Low Imageability 24/30

TDS requested repetition of twenty-two items before responding, sometimes requiring two or three repetitions. This frequent need for repetition indicates that TDS was having difficulty in accessing or maintaining representations. Fourteen of these items were low imageability pairs, suggesting a semantic aspect to his processing difficulty. Of the twenty-two repeated items he subsequently made errors on five. His overall score is thus much lower if correct responses following repetition are scored as errors (35/60). TDS also showed a stronger effect of imageability when repetitions were taken into account:

High imageability 22/30
Low imageability 13/30

This effect was significant (chi square p =.018*). Whilst repetition may assist his auditory processing, it is not always sufficient to enable him to access the correct semantic representations. The results of the set of auditory input assessments suggest that TDS is able to access the appropriate semantic field from spoken words, and is generally able to process fine semantic distinctions (at least for highly imageable nouns). However, he does have some impairment of access to semantics from auditory input. This is only apparent when processing demands are high, such as when making judgements about low imageability words or when distractors are both semantically and visually related to the target.

TDS has significant difficulties in processing syntactic relations in spoken sentences. He scored 53/80 on the **TROG**, with a further six correct responses following repetition of the stimulus. He passed 8/20 blocks and was able to process all of the lexical items (nouns, verbs and adjectives), as well as the two- and three-element combinations. He was also able to process morphological markers of plurality, as well as the '*not only X but also Y*' construction. He made errors on all other syntactic relations tested, and requested repetitions of many items on those blocks that he failed.

On **Sentence Semantic Anomaly Judgement** TDS scored 15/16. This suggests that, in spite of his syntactic processing difficulties, TDS is usually able to process and integrate the core lexical-semantic representations within a sentence. Although overall TDS made correct judgements, it was evident that he was having some difficulty in processing the input, since he requested repetition of five out of the sixteen sentences before responding. He made one error in rejecting the sentence '*That dog chased after a stick*'. It was noted that he had responded very rapidly to this item compared to the others, therefore perhaps not fully processing it. Thus, TDS does have a mild difficulty in processing sentence semantics (that may arise from his difficulties in processing single words), as shown by his need for repetition.

Visual input

TDS's processing of written language is much better preserved than his processing of spoken language. He made no errors on **Letter Discrimination: Mirror Reversal** (36 /36) showing that he is able to recognise letter-forms. On **Visual Lexical Decision** he scored 115/120, with his only errors on nonwords. While performance on words is normal, accuracy for nonwords falls slightly below the normal range.

TDS has relatively good access to semantic representations from written words, and made no errors on **Written Word-Picture Matching** (40/40). He was able to respond without hesitation to all but one item, the word *thumb,* for which he was hesitant in deciding between the target picture and that of the close semantic and visual distractor *finger.* Although his access to semantics from written words is better than from spoken words, it may also be affected by a mild deficit in distinguishing between word meanings that are both semantically and visually related.

On **Written Synonym Judgement** TDS scored 56/60, which is at the bottom of the normal range. There appeared to be some effect of imageability, as all of his errors involved rejection of synonymous low imageability pairs (*blame-reproach, detection-discovery, chance-luck, advice-counsel*). Following the assessment TDS explained that at times he might have been confused by the multiple meanings or homophony of some of the items, perhaps generating a meaning other than that intended by the test. He was quite explicit about this, using a dictionary entry of a word with multiple meanings as an example to make his point, and this may well account for his rejection of the same pairs. For instance, on *detection-discovery* he explained that he had thought of *detection* in policing terms (being a policeman himself) but of *discovery* in scientific terms, hence his negative response. Similarly, he thought of *chance* in the sense of 'take a chance' but *luck* in the sense of 'having good luck'.

TDS's ability to process sentences is very similarly impaired for both spoken and written input. On the written presentation of the **TROG** he scored 49/68. He passed eight blocks, including the comprehension of nouns, verbs, adjectives, and two- and three-element combinations. He accurately processed plural pronouns (though not plural inflections), comparatives, and the 'not only but also' construction. He made errors on all other syntactic relations tested. The test was discontinued after seventeen blocks as TDS was becoming frustrated.

Spoken Output

In conversation TDS's spoken output consists mainly of clearly articulated and well-intonated phrases, but with a paucity of specific referential nouns and verbs. Many of his phrases are syntactically well structured using light verbs (frequently 'getting' or 'trying'), but sentence structure is disrupted by lexical retrieval difficulties. This results in frequent paraphrasing as he attempts to reformulate his output. Attempts to retrieve specific lexical items occasionally result in neologistic output. Where he is unable to retrieve specific words, TDS is highly adept at using gesture, pointing, materials such as maps and diaries, or writing the first letter to convey his meaning. These strategies indicate that TDS has well defined representations at the message level even when unable to express these using speech.

On **Nonword Reading** TDS scored 0/24. He made between two and five attempts to read each item, with each attempt being a single syllable that usually bore no clear phonological relation to the target. For instance he read the nonword *fon* as '[ni]...[nim]...[nim]...[nim]'. Some responses were certainly lexicalisations, although again relation to the target was uncertain. For instance, for the nonword *nar* TDS said 'threw...[ni]...sleep...no'. It is possible that *nar* was lexicalized to *nap*, and then read as *sleep*. This indicates that TDS is unable to use grapheme-to-phoneme conversion rules in order to access the phonology of written nonwords.

TDS was only able to name the first item in **Spoken Picture Naming** (1/40), and this took thirteen attempts. He made multiple attempts to name each item, comprising a series of syllables that were often related to each other but bore little relation to the target. For instance:

bear [ʃ] [ʃni] [n] [n] [sni] [sli] [s] [si] [si]

horse [ʃu] [kʌm] [kʌm] [kʌmˈli] [kənɛə] [kɒlm] [kɒ] [kɒlm] [kɒl] [kɒl] [kɒːl] [kɒl] [kɒl] [kɒm] [ʃə]

TDS was aware both of his errors and of when he correctly named the first item. The test was discontinued after six items as it was causing him frustration and some distress.

TDS produced lengthy responses to all items on **Spoken Event Description**, mainly consisting of multiple revisions of incomplete phrases and sentences. Accompanying gestures and contextual cues sometimes gave information about those elements of the event that TDS was unable to express linguistically. For example, his description of the item in which a woman punches a man was:

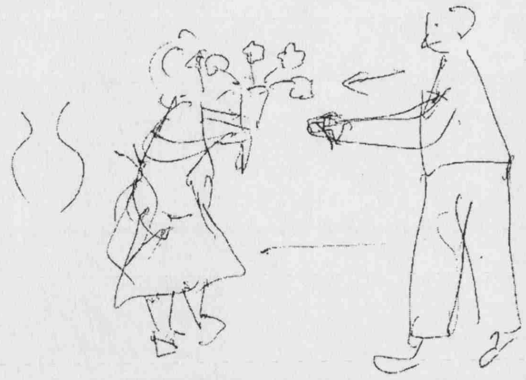
> "different...same one but different...you're trying to get for me...you're trying to get your...you're trying for me for the back...what is the that one...like for me I'm wait, I'm wait, I'm nothing...but you're getting...so she's getting...she's getting what it is *[sɪm] [kɪm]* no...she's getting *[tɪʃ] (gestures punching)."*

TDS used the pronoun '*me*' to refer to the male participant and '*you*' to refer to the female participant (he was speaking to the female researcher). This is consistent with his use of the same strategy to refer to men and women in conversation. Overall TDS has relatively good access to syntactic structures in spoken output, but is severely impaired in lexical access. His use of a combination of incomplete phrases constructed around mainly light verbs, idiosyncratic but consistent referential phrases, gestures and contextual cues suggest that he has access to rich representations at the message level.

Written Output

TDS's ability to write is severely impaired, with performance on **Written Picture** Naming (1/40) showing difficulties at both semantic and lexical levels. He only attempted the first seven items, after which he asked to discontinue the test. He made multiple attempts to write the name of six items, with only one attempt resulting in a correct spelling (for item 1 *comb* he wrote *cohs cont coat comb*), and he made one clearly semantic error (for item 7 *glove* he wrote *foot*). Several attempts consisted of a single letter without a clear relation to the target, or an incomplete word that suggested he had partially accessed an appropriate lexical target. For instance, for item 2 *bear* he wrote: *c bi_g po*, before looking up the word 'polar' in his dictionary and copying it out.

For **Written Event Description** TDS did not produce any attempts at writing, but did however produce a detailed drawing of each event. These drawings successfully conveyed information about the participants, themes, instruments and directionality of all the events, in keeping with the information conveyed by the control group. For instance, for the item in which a man gives flowers to a woman TDS drew the actor (the man), the recipient (the woman), and the theme (the flowers). TDS explicitly conveyed the recipient's gender both through her clothing and by drawing 'female curves' beside her. The nature and directionality of the event was expressed by the actor's outstretched arms, the recipient holding the flowers, and an arrow pointing from the actor to the recipient:



It therefore appears that TDS has normal representations of events at the message level, but is unable to express this information in written language due to severely restricted access to orthographic output forms.

Summary of TDS's profile

In processing auditory input, TDS presents with difficulties at both phonemic and lexical levels, as well as slight difficulties in accessing semantic representations from spoken words. Although he has high levels of accuracy in formal test scores, his processing difficulties are apparent both in frequent requests for repetition and at times in uncertainty over his responses. His processing of written words is better, with test results falling within the normal range. It is suggested that TDS may however have a very mild deficit in central semantic processing that is apparent when he is asked to make judgements about pictured word meanings that are closely related both semantically and visually. TDS is able to process a restricted range of syntactic structures in both spoken and written sentences, and is able to make judgements about semantic relations within spoken sentences. His output is very impaired in both spoken and written modalities, with speech characterised by incomplete phrases and sentences that are often constructed around light verbs and idiosyncratic referential terms. He has great difficulty in retrieving specific lexical items for speaking, although he clearly has rich representations at the message level which he conveys through a range of communication strategies. His writing is also severely impaired, although he can sometimes write the first letter of a word accurately. He is sometimes able to look up a word in a dictionary when he is unable to say it, indicating that he has a clear semantic and lexical target in mind.

Profile of TVR

Background Information

TVR, a fifty-three year old man, had been aphasic since a left parietal infarct when he was aged fifty-one. This stroke resulted in right hemiparesis, right facial weakness, right neglect and severe dysphasia. TVR was sixteen months post onset of aphasia when he joined the study.

Before his stroke TVR worked as a lorry driver, and had progressed to become distributions manager for a large company. This role had required him to handle written information efficiently. He had been unable to return to work since his stroke. TVR had recently started attending an archaeology adult education class, and reported enjoying the presentations. He was living with his partner who was his main carer, and attending a local aphasia day unit on two days a week.

Screening Assessments

Pure tone audiometry revealed that TVR has a very mild bilateral hearing loss at higher frequencies.

Frequency Hz	Hearing Level dB (right ear)	Hearing Level dB (left ear)
1000	5	10
2000	20	20
4000	25	35

Nonword Phoneme Discrimination

TVR scored a total of 107/126 (85%). This is below the normal range (96-99%) and indicates an impairment of phoneme discrimination. He made errors on both same and different pairs:

same pairs	58/64	91%
different pairs	50/62	81%

Auditory Lexical Decision

TVR scored a total of 145/160 (91%), which is just outside the normal range (93-99%). He made more errors on nonwords:

words	75/80
nonwords	70/80

Profiling assessments

Visual-semantic processing

On the **BORB Object Decision** test TVR scored 19/32, which is far below the normal range (controls scored 28-32 correct). The only items that he accepted were the three real tools; that is, he rejected all thirteen of the real animals. This was somewhat surprising since neither the researcher nor TVR's clinician had previously observed any signs that he might have a visual processing impairment. Following the test the author informed TVR that some of the items that he had rejected were in fact real. He was invited to look at the pictures again and try to identify those that represented real items. On this second occasion TVR scored 31/32 which is well within the normal range. Attempts were made to establish why he had previously rejected all the animals, but given his communication difficulties it was not possible to identify any factors that had led him to make errors on the first testing. The results of this assessment are inconclusive. It is possible that TVR has a slight visual processing impairment, but that he was able to overcome this when he paid closer attention to the task on his second attempt. However, there was little other indication (either during other formal assessments using pictorial stimuli, or from observations of his behaviour in the clinical and social environment) that he had a visuo-perceptual impairment. Another possibility is that TVR had misunderstood the task instructions, or initially rejected the real animal items due to the quality of the line drawings in the BORB test materials.

He scored 49/52 on **Pyramids and Palmtrees,** which is at the lower end of the normal range. This indicates that TVR is able to access semantic representations from pictures, and to process those semantic and pragmatic relations tested. His performance on this test is not strongly suggestive of a visuo-perceptual impairment, making it more likely that his errors on the BORB Object Decision were due to inattention or misunderstanding of the task.

However, TVR made a number of errors on the **Role Video Test** where he scored 11/16. Two of his errors involved misidentification of the theme of the event. For example, for the item in which a cup is smashed and choice of pictures includes an unbroken cup, a broken cup and a broken plate, TVR selected the broken plate. Two of his errors involved reversal of the agent/goal relationship. For instance, in the item in which a man throws a ball to a woman and the choice of pictures includes the man with a ball, the woman with a ball, and the woman with a camera, TVR selected the man with a ball. The fifth error involved misidentification of the nature of the event. This involved the item in which a banana is being mashed and the choice of pictures include a mashed banana, a sliced banana and a mashed avocado. TVR selected the sliced banana.

Although available normative data is limited, it suggests that normal performance is 100% on the full 32-item test (Jane Marshall, personal communication). TVR's performance on this task is clearly below normal, and indicates that he may have some difficulty in processing a number of aspects of events, which may have implications for his ability to predict likely words based on preceding context. However, it should be noted that TVR displayed no signs of non-linguistic cognitive or perceptual difficulties in his behaviour and day-to-day interactions. Both the researcher and TVR's speech and language therapist were somewhat surprised by the difficulties that he experienced with this task.

In order to gain further information about TVR's event processing difficulties and how these might relate to his formulation of linguistic output, he was asked to select the appropriate outcome pictures for the remaining sixteen role video clips. (These clips were those used for the spoken and written event description tasks, and so would not usually have been used to test event processing). For each item, TVR was shown the video clip, then asked to verbalise (items 17-24) or write (items 25-32) a description of what he had seen. (His descriptions are presented later in this chapter). Following this he was requested to select the appropriate outcome picture for the video clip. For these items he scored 15/16 in selecting the outcome pictures. His only error was a reversal of the agent/goal relationship for the item in which a woman sells a camera to a man, although he correctly assigned these roles in his verbal description of the event. This performance is considerably better than for the first sixteen items. While it is not possible to draw firm conclusions about why his performance here was better, one possible reason is that his attempts to formulate linguistic descriptions of the events assisted in focussing his attention.

Auditory input

TVR scored 54/60 on **Auditory Rhyme Judgement**. Errors all involved word pairs that differed in their vowel (e.g. gull-full), but which he judged to be rhymes[24]. These errors do not appear to be based on spelling patterns, since TVR's accuracy was the same for spelling pattern controls and phonological controls:

Spelling pattern rhyme	15/15
Spelling pattern control	12/15
Phonological rhyme	15/15
Phonological control	12/15

It is possible that TVR has difficulty in encoding vowels, but no further evidence of this is available since the phoneme discrimination tests used in this study only contrast consonants.

On **Spoken Word-Picture Matching** TVR scored 39/40, which is within the normal range. His only error was on the item *crown* where he was unable to choose between the pictures of *crown* and *tiara*, which are both semantically and visually related. He made more errors on **Auditory Synonym Judgement,** where he scored 47/60 which is below the normal range. He showed an effect of imageability with most of his errors involving low imageability items:

High Imageability	26/30
Low Imageability	21/30

These two assessments suggest that TVR has difficulty in accessing semantic representations from auditory input, affecting mainly low imageability words.

The **TROG** revealed that TVR has difficulty understanding some types of spoken sentence. He scored 66/80 and passed a total of eleven blocks out of twenty. These included the lexical blocks testing nouns and verbs, but not adjectives. He also passed the two- and three-element combinations, verb negation, personal pronouns, plural inflections, and reversible active sentences. The only complex sentence structure that he understood was 'not only x but also y'. TVR is, however, able to process and integrate the core lexical-semantic representations within spoken sentences, since he made no errors on **Sentence Semantic Anomaly Judgement** (16/16).

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[24] While dialectal variation could mean that pairs such as *gull-full* are rhymes in some accents, this was not the case for TVR who had a Southern British English accent.

Visual input

TVR made two errors on **Letter Discrimination: Mirror Reversal** (34/36). This suggests that his thresholds for letter recognition may be slightly lowered, resulting in his acceptance of two of the reversed letters (*g* and *D*). While this may be a factor affecting only the processing of written letter-forms, it is also possible that it may reflect a more general instability in visual processing (perhaps contributing to his errors on the BORB, and his one visual error on written word to picture matching). He also shows a mild impairment of written word recognition. On **Visual Lexical Decision** he scored 110/125, and made more errors on words than nonwords:

words	53/60
nonwords	57/60

Although he makes few errors overall, he shows a clear effect of the interaction between imageability and frequency, since six of the seven words that he rejected were rated low on both these parameters (e.g. *pact, plea, realm*). This indicates that he has some difficulty in accessing semantic representations from written input. Further evidence to support this suggestion comes from his performance on **Written Word-Picture Matching**, where he scored 36/40. His errors were dispersed across the different types of distractor, suggesting that he did not always access the correct semantic field. One error involved a close semantic distractor (*belt* ⇒ *braces*), and one involved a distant semantic distractor (*pipe* ⇒ *ashtray*). For one item he selected the visual distractor (*shoe* ⇒ *peanut*), and for another he chose the unrelated distractor (*bell* ⇒ *battery*). It was observed that TVR's response to the item *bell* had been very slow compared to the other items.

TVR's difficulties in accessing semantic representations of written words were most apparent in **Written Synonym Judgement**, where his score was below the normal range and at the level of chance (31/60). This compares with an overall score of 47/60 on auditory synonym judgement, suggesting that his access to semantic representations from written words is particularly impaired. He made more errors on the low imageability pairs, but there was no significant effect of imageability (chi square p =.196):

High Imageability = 18/30
Low Imageability = 13/30

TVR's understanding of written sentences is considerably more impaired than his understanding of spoken sentences. On the written presentation of the **TROG** he scored 51/80 and passed seven blocks out of twenty. He passed the blocks testing lexical contrasts in nouns and adjectives but not verbs, and was able to comprehend the two- and three-element combinations, plural pronouns and inflections. Interestingly, he made a reversal error on the active reversible sentences, but responded correctly to all the passive reversible sentences. He made errors on all other syntactic structures tested.

Spoken output

TVR's spoken output is severely impaired, both in conversation and on formal testing. In conversation, he tends to rely on his conversation partner to ask him questions that can be answered yes or no, or to provide him with a choice of written words to choose between. His spontaneous speech is almost entirely restricted to the words and phrases: "yes" "no" "um" "but, er" "no, I can't" and "well, it's er…". He sometimes draws a picture or writes the first letter of words he cannot say.

Formal assessment revealed that TVR's spoken output breaks down on a number of levels. He has a severe impairment of the ability to use grapheme-to-phoneme conversion rules, and on **Nonword Reading** scored 0/24. He attempted to read every item between one and three times, but most of his responses were phonologically unrelated to the target (e.g. *cug* → [mls]). In total he produced 111 phonemes in his responses, of which only 18 were correct. None of the targets were read aloud correctly, and TVR showed awareness of his errors. In discussion following this task, TVR indicated that he had been unsure how to pronounce the items (i.e. how to access the phonology from the written forms), but that his actual productions had matched his internal representations and were not the result of motor speech impairments.

On **Spoken Picture Naming** TVR scored 0/40. He attempted a response to thirty-three items, but did not name any pictures correctly. He made a number of types of error. For six items (including *bowl, eye, and dog*) his only response was to say 'no', while on another four items which occurred sequentially (*screw, anchor, glove, belt*) he showed evidence of perseveration on the word '*number*' (after the researcher had said 'number five'). For the remaining twenty-three items TVR attempted to say the name. He made at least two attempts to name most of these, often demonstrating a pattern of *conduite d'approche*, suggesting that he had access to at least partially correct phonological information (e.g. for *wristwatch* he said [bɪsbəʊ] then [wɪsbəʊ]). For nine items, at least one of his responses bore some phonological similarity to the target, usually with at least a correct vowel segment (e.g. *mountain* [ɑʊtɪn], and *elephant* [ˈɛfəmənz]). For these items at least it seems clear that TVR had accessed the correct lexical target. A further three responses apparently showed phonological similarity to a semantically related word e.g. *fork* [puː] (similar to 'spoon'), *bread* [dəʊf] (similar to 'loaf'). The task was discontinued after item thirty-three due to TVR's lack of success and increasing frustration.

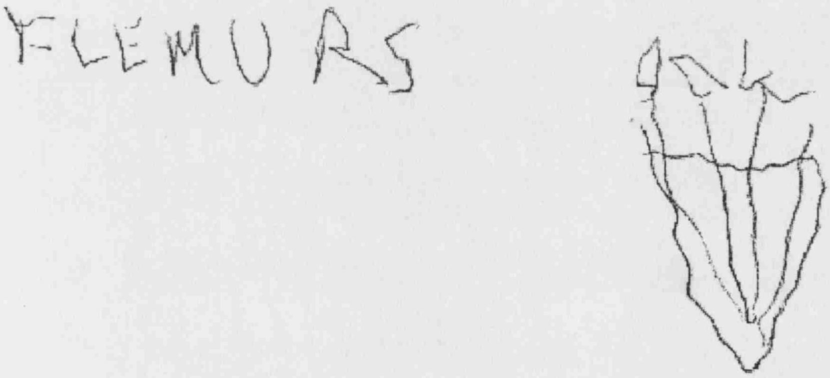
These results are in keeping with TVR's severely restricted spoken output in spontaneous speech. His pattern of errors suggests that his output is impaired on a number of levels. It appears that at times he is unable to generate any specific semantic and/or lexical target, while at other times he generates a semantically related target. Most of his errors appear to arise from difficulties in accessing full and accurate phonological representations, with the possibility that he has additional difficulties in motor programming (which were not specifically assessed).

On **Spoken Event Description** TVR provided a spoken response to five of the eight items. In two of these his response contained evidence of an appropriate verb and argument structure, with all of the participants in the event represented. This output was much more elaborate than his speech in conversation. For instance, following the video clip of a man punching a woman, TVR responded *'He hit her'.* Also, following the clip in which a woman sells a camera to a man, he responded *'She...*[Iflz]...[Im]*...a...*['æmə]*'* (for which the underlying target may have been 'She gives him a camera'). This response is particularly interesting, since it appears that TVR correctly generated a sentence built around a three-argument verb. For the item in which a woman writes and sends a letter to a man, TVR's response contained both the participants (albeit renamed) but lacked an appropriate verb – *'Thomas...Penny...she...she...spike.'* It may be that TVR was unable to select an appropriate verb here since several actions take place in the scene (writing, putting into an envelope, sealing, and posting) making it difficult for him to narrow down his selection to one. His other two responses were less complete, and showed evidence of struggling to access lexical targets. For instance, following the clip in which a woman folds a newspaper, TVR responded '[skɒ] [ɛts] [ɛts]', while for the clip in which bread is being sliced, he responded *'She...* [iː] [ɒɹəʊ]... *she...* [tɒɹəʊ]*'.*

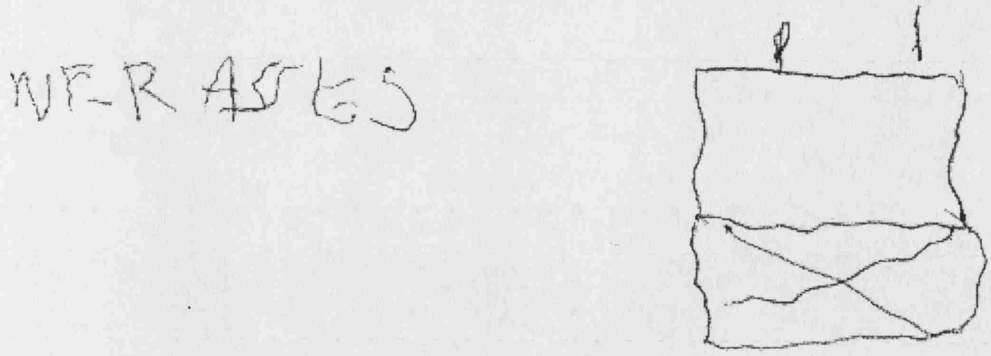
Written output

TVR's written output is limited, but less restricted than his spoken output. On **Written Picture Naming** he scored 5/40. He was able to produce a written response to all but one picture (*bear*). In contrast to his performance on spoken picture naming he produced only one attempt at each item. Although only five of his responses were correct, there was evidence that he had (at least partially) accessed the correct lexical target for the majority of items. For thirty-three of his responses he wrote at least the initial letter correctly (e.g. *comb* – 'COUM', *anchor* – 'ACHISTINN', *knife* – 'KNATING) and often had many of the correct letters present (e.g . *mountain* – 'MOUNTINS). Some of his responses appeared to be straightforward lexical errors (e.g. *horse* – 'HOUSE'), whilst a quarter of his responses contained superfluous syllables (e.g. *arrow* – 'ARONANUE'). There was no effect of spelling regularity on his accuracy of response suggesting that he was using his (impaired) lexical route to spelling.

TVR produced one written word together with one drawing in response to each item for **Written Event Description**. In all his responses TVR represented at least one relevant element of the event, but he did not represent all the key participants in any of the events. For seven out of the eight items TVR drew a single object that constituted either the theme or the instrument of the event. For instance, for the scene in which a woman shoots a man, he drew a gun, while for the scene in which a woman closes a suitcase, he drew the suitcase. In none of his responses were the human participants represented (except somewhat obliquely as a pair of feet for the scene in which a man trips up a woman). In addition to these drawings he wrote one word for each item. Three of these words constituted the names of the drawn items (although with spelling errors) and thus did not add any descriptive information; e.g. for the scene in which a man gives flowers to a woman, he wrote 'FLEMURS' and drew a bunch of flowers:



In a further three responses the written word appeared to be an inflected verb describing the nature of the event (although again with spelling and/or lexical errors). For instance, for the scene in which a potato is being peeled he wrote 'PUTCHING' and drew a potato. In his remaining two responses the underlying target for the written word was unclear. For instance, for the item in which a woman closes a suitcase he wrote 'NERASSES':



In summary, TVR's performance on this task shows that he is able to convey some key elements of an event using a combination of writing and drawing. However, his output tends to represent only the inanimate participants in the event together in some instances with limited information about the nature of the event. Human participants and elements such as directionality and change of state are not represented.

Summary of TVR's assessment profile

TVR presents with aphasia affecting comprehension and production of both spoken and written language, with also the possibility of a mild impairment of visual processing. The results of assessments of visual processing were, however, difficult to interpret. While his first attempt at the object decision test produced a performance that was well below the normal range, on his second attempt performance was normal. Performance on Pyramids and Palmtrees was at the lower end of the normal range suggesting he is able to access semantic representations from pictures, but he did make one visual error on written word-picture matching. Assessment of visual processing is therefore inconclusive. TVR's processing of auditory input is impaired. He presents with moderate difficulty in phoneme discrimination, where he made errors on both same and different pairs. His ability to recognise spoken words is mildly impaired, with performance on lexical decision falling just below the normal range. He also has difficulty in accessing semantic representations from auditory input, shown particularly by his errors on low imageability pairs in auditory synonym judgement. TVR's processing of written words is also impaired. He made two errors on letter discrimination, which may have been related to a visual processing difficulty. Recognition of written words is mildly impaired, and interestingly TVR made more errors on words than nonwords in visual lexical decision. His ability to access the meanings of written words is severely impaired, as shown by his errors across all distractor types on written word to picture matching, and his performance at chance level on written synonym judgement. Performance on the TROG also revealed a more severe impairment in comprehension of written than spoken language, and TVR was able to make accurate judgements about spoken sentences in sentence semantic anomaly judgement. TVR has very limited spoken output both in conversation and in test situations. He is able to produce a number of social phrases but otherwise has almost no spontaneous speech. However, his performance on spoken picture naming indicated that he was able to generate partial phonological representations for about a quarter of the items. Written output is also severely impaired with few words correctly spelled. However, TVR's performance on written picture naming revealed that he is usually able to access partial orthographic representations with at least the initial letter correct in most responses.

Summary of chapter three

A language processing profile of each of the aphasic participants has been presented, with a deficit in auditory processing demonstrated in each case. Since environmental sound recognition was not tested with these participants, we cannot rule out the possibility that these speech perception deficits may co-occur with a more generalised auditory agnosia. However, it was argued in chapter one that auditory agnosia and speech perception deficits in aphasia are dissociable – therefore the speech perception deficits may legitimately be explored separately from consideration of environmental sound recognition. It is also possible that these participants have deficits in early auditory processing, as reported in some published cases of pure word deafness, but this area has not been tested apart from pure tone audiometry. The phoneme discrimination difficulties of the five aphasic participants are certainly similar to those reported in cases of word sound deafness, as will be shown further in chapter five. However, none of these participants meet the definition of pure word deafness, since all of them display a range of significant aphasic deficits across spoken and written language comprehension and expression. Even the loose definition of word deafness given by Buchman et al (1986 p.498) as 'a disparity between auditory verbal comprehension and other linguistic functions' does not fit these participants; for instance, results of spoken picture naming reveal that they are each severely impaired in spoken output. The aphasic participants can perhaps best be described as showing features that are similar to those found in word sound deafness, but in the context of a much broader profile of aphasic deficits.While there are similarities within the group in that each individual is impaired in phoneme discrimination, there are many differences between them in other aspects of processing. These individual patterns will be used to illuminate the results of the more detailed investigations of auditory processing presented in the next three chapters. The first experiment that will be described is an investigation of factors influencing spoken word recognition.

AL Language Profiling Assessments		Results
Visual – Semantic Processing		
	BORB Object Decision (easy)	28/32
	Pyramids & Palmtrees (three picture)	47/52
	Role video	15/16
Auditory input		
	Auditory Rhyme Judgement	21/30
	Spoken Word-Picture Matching	37/40
	Auditory Synonym Judgement	27/36
	TROG (spoken)	33/64 5 blocks
	Sentence Semantic Anomaly Judgement	15/16
Visual input		
	Letter Discrimination (mirror reversal)	35/36
	Visual Lexical Decision	83/120
	Written Word-Picture Matching	26/40
	Written Synonym Judgement	37/60
	TROG (written)	29/64 2 blocks
Spoken output		
	Spoken Picture Naming	0/40
Written output		
	Written Picture Naming	0/40

Table 2. Summary of results of profiling assessments for AL

JW Language Profiling Assessments	Results
Visual – Semantic Processing	
BORB Object Decision (easy)	31/32
Pyramids & Palmtrees (three picture)	49/52
Role video	16/16
Auditory input	
Spoken Word-Picture Matching	32/40
Auditory Synonym Judgement	23/60
TROG (spoken)	42/52 10 blocks
Sentence Semantic Anomaly Judgement	16/16
Visual input	
Letter Discrimination (mirror reversal)	34/36
Visual Lexical Decision	103/120
Written Word-Picture Matching	31/40
Written Synonym Judgement	49/60
TROG (written)	43/64 6blocks
Spoken output	
Nonword Reading	0/24
Spoken Picture Naming	2/40
Written output	
Written Picture Naming	1/40

Table 3. Summary of results of profiling assessments for JW

JWh Language Profiling Assessments	Results
Visual – Semantic Processing	
BORB Object Decision (easy)	32/32
Pyramids & Palmtrees (three picture)	47/52
Role video	16/16
Auditory input	
Spoken Word-Picture Matching	38/40
Auditory Synonym Judgement	47/60 51/60 with repetition (52/60*)
TROG (spoken)	38/52 9 blocks
Sentence Semantic Anomaly Judgement	16/16
Visual input	
Letter Discrimination (mirror reversal)	36/36
Visual Lexical Decision	109/120 118/120*
Written Word-Picture Matching	39/40
Written Synonym Judgement	58/60
TROG (written)	35/56 4 blocks
Spoken output	
Nonword Reading	1/24
Spoken Picture Naming	19/40
Written output	
Written Picture Naming	10/40
	* retest score

Table 4. Summary of results of profiling assessments for JWh

TDS Language Profiling Assessments		Results
Visual – Semantic Processing		
	BORB Object Decision (easy)	31/32
	Pyramids & Palmtrees (three picture)	52/52
	Role video	16/16
Auditory input		
	Auditory Rhyme Judgement	41/60 46/60 with repetition36/40
	Spoken Word-Picture Matching	40/40 with repetition
		35/60
	Auditory Synonym Judgement	52/60 with repetition
		53/80 8 blocks
	TROG (spoken)	
		15/16
	Sentence Semantic Anomaly Judgement	
Visual input		36/36
	Letter Discrimination (mirror reversal)	
		115/120
	Visual Lexical Decision	
		40/40
	Written Word-Picture Matching	
		56/60
	Written Synonym Judgement	
		49/68 8 blocks
	TROG (written)	
Spoken output		0/24
	Nonword Reading	
		1/40
	Spoken Picture Naming	
Written output		1/40
	Written Picture Naming	

Table 5. Summary of results of profiling assessments for TDS

TVR Language Profiling Assessments	Results
Visual – Semantic Processing	
BORB Object Decision (easy)	19/32 retest 31/32
Pyramids & Palmtrees (three picture)	49/52
Role video	11/16
Auditory input	
Auditory Rhyme Judgement	54/60
Spoken Word-Picture Matching	39/40
Auditory Synonym Judgement	47/60
TROG (spoken)	66/80 11 blocks
Sentence Semantic Anomaly Judgement	16/16
Visual input	
Letter Discrimination (mirror reversal)	34/36
Visual Lexical Decision	110/120
Written Word-Picture Matching	36/40
Written Synonym Judgement	31/60
TROG (written)	51/80 7 blocks
Spoken output	
Nonword Reading	0/24
Spoken Picture Naming	0/40
Written output	
Written Picture Naming	5/40

Table 6. Summary of results of profiling assessments for TVR

Chapter 4 Lexical, Semantic and Sentence Context Effects on Auditory Word Recognition

Introduction

A number of factors are known to influence the ease with which words are recognised. These include properties of the words themselves, such as frequency and imageability, as well as aspects of the context in which they are processed (see chapter one). An experiment was designed to explore the interaction between word properties and linguistic contexts during the process of word recognition. This experiment sought to address two main questions. The first is whether the effects of word frequency and imageability on recognition of words in isolation exert a similar influence when words are heard in the context of a meaningful sentence. Secondly, this experiment explored whether the factors that influence auditory word recognition in normal processing are of similar importance to aphasic listeners.

This experiment used two versions of auditory lexical decision to explore the effects of word frequency and imageability, as well as of sentence contexts, on word recognition. The two tasks were simple auditory lexical decision and sentence auditory lexical decision. In the simple auditory lexical decision task, participants heard an item and were asked to judge whether the item was a word or not. In the sentence auditory lexical decision task participants heard the same items as in the simple lexical decision task, but each item was presented at the end of a predictive sentence. Following initial analyses a further factor, neighbourhood density, was also considered. The effect of each factor was considered separately for control and aphasic participants, and compared across the two tasks.

Method

Participants

Two groups took part in the experiment, a group of five aphasic listeners (who were described in chapter three), and a group of ten controls. The control group sample is summarised in Table 7.

Controls	Sex	Age	Education	Occupation
AT	M	54	Graduate	Businessman
DB	M	54	Left school aged 15 – no formal qualifications	Taxi driver
DT	M	55	Art college graduate	Graphic designer
GH	M	63	Left school aged 18 – educated to A'level standard	Shopkeeper
JH	F	57	Educated to A'level standard plus teaching diploma	Shopkeeper and retired nursery teacher
JS	M	40	Graduate	Civil servant
MC	F	37	Left school aged 16 – educated to CSE standard	Home maker and cook
RM	M	41	Music graduate	Unemployed musician
SF	F	50	Left school aged 16 plus art diploma	Artist
WB	F	37	Graduate	Home maker

Table 7. Summary of control group participants

Stimuli

There were one hundred and sixty items in each test. In the simple task, eighty items were English words and eighty were phonologically legal nonwords. Each nonword item was phonologically similar to one word item. There were four sets of word items, balanced for imageability and frequency. In the sentence task each item consisted of a sentence frame that was completed by a test word or nonword. Test words and nonwords were the same as those used in simple auditory lexical decision. There were eighty sentence frames. Each sentence frame was presented twice; on one occasion the sentence frame was completed by a word, and on one occasion it was completed by a nonword. Sentence frames were congruent with, and highly predictive of, the corresponding test word. Where the sentence frame was completed by a nonword, it was completed by that nonword that was phonologically derived from the congruent word.

The stimuli in this experiment were adapted from the PALPA 5 auditory lexical decision task (Kay, Lesser, & Coltheart 1992). This task was selected since a) it is a widely used test of spoken word recognition in aphasia, b) it had been designed to reveal effects of both frequency and imageability, and thus should contribute to investigation of interactions between lexical and semantic levels of representation in word recognition, and c) had published normative data available. The task was adapted to create a sentence context condition, and to try to ensure that stimulus sets were balanced particularly in relation to the sentence context task.. One potential problem identified in relation to the published task was that the items included considerable variation in how the nonword items had been derived from the word items. Although all the nonwords were phonologically legal in English, some nonwords were phonologically very similar to the corresponding word item (e.g. purpose/purpise) while others were very distinct (e.g. alcohol/halocle) and had no immediate phonological neighbours. It was considered possible that these factors might influence both accuracy and speed of response to nonword items in the lexical decision tasks. This was of particular concern with regards to the sentence context version of lexical decision, since the preceding sentence context is assumed to prime a set of semantically plausible words that might complete it. The degree to which a nonword item differs from its related word item might therefore be expected to influence the speed and/or accuracy of the response to that nonword. Unless the distribution of items across stimulus sets were adequately controlled for these factors, there was therefore the possibility of introducing artificial differences in performance on the different sets that might be wrongly attributed to the effects of word frequency or imageability.

A comparison of closeness of match between word and derived nonword stimuli in PALPA 5 was therefore carried out to examine whether there were any differences in the distribution of closely and distantly matched word-nonword items across the four sets of words. First the phonological form of each word and nonword was specified. Where the syllable structure of the nonword differed from that of the word (e.g. session/settion) this difference was eliminated by modifying the nonword. Other nonwords were modified either because they are valid dialectal pronunciations of English words (e.g. theory/pheory), or because the difference between the word and nonword was considered too slight to be reliably perceptible (e.g. principle/prisciple). A comparison was made between the form of each word and its corresponding nonword to identify a) how many phonemes were in the word, and b) how many of the phonemes in the nonword differed from the phoneme in the corresponding syllable position in the word. These values were then summed across each stimulus set to allow for comparison across the four sets. This revealed that distributions were not even across groups. The High Imageability/ High Frequency group showed greater differences between words and their corresponding nonwords than the other groups. A number of the nonword items in this group were therefore modified in order to produce both a proportion of differing phonemes and pattern of difference types which was more closely matched to the other groups. The result of these revisions on the relatedness of word and nonword items, expressed as the number of differing phonemes / number of word phonemes across all items in a set, is shown in Table 8. It can be seen that the four sets appear well balanced.

Lexical Decision Items	High Imageability	Low Imageability	Totals
High Frequency	29/ 96	28 / 107	**57 / 203** (28%)
Low Frequency	26 / 94	28 / 96	**54 / 190** (28%)
Totals	**55 / 190** (29%)	**56 / 203** (28%)	

Table 8 Phonological relatedness between word and nonword items in revised auditory lexical decision stimuli.

It was however apparent that there were differences not only in the number of phonemes which differed between each word and its corresponding nonword, but also in the degree to which the phonemes differed. For each phoneme which differed between the word and corresponding nonword forms, the degree of difference was therefore analysed in terms of whether the phoneme was a vowel or consonant, and if a consonant by how many distinctive features the word form had been altered to derive the nonword. Insertion or deletion of an entire phoneme was classed as a three feature change. These figures were then summed across each stimulus set to allow comparison between sets. The results of this analysis are expressed in terms of the percentage of each category of phoneme change within each stimulus set (Table 9). It can be seen that the resulting four sets of word stimuli now show similar distributions of phonetic relatedness to the corresponding sets of nonwords, and so these items were used in testing.

	V	C 1 feature	C 2 features	C 3 features
Hi I Hi F	39 %	10%	21%	31%
Hi I Lo F	31%	8%	27%	35%
Lo I Hi F	36%	4%	19%	43%
Lo I Lo F	46%	4%	19%	32%

Table 9. Percentage of phonetic difference types between word and nonword items in revised auditory lexical decision stimuli.

For the sentence lexical decision task, a sentence frame was devised corresponding to each word item. These sentence frames were designed so that the word item would provide a syntactically, semantically and pragmatically appropriate completion to the sentence. For instance, the sentence frame '*The artist painted a ...*' could be completed by the target word '*picture*'. In each case there were also other words that could have completed the sentence (e.g. in the example given, among the many candidates might be *portrait*, *landscape*, *mural*, *scene* or *cherub*), with the target word being considered one of the more likely candidates. Sentence frames were generated such that the distribution of a) the number of words in the frame that primed the target word, and b) the number of each type of sentence frame (in terms of canonical structures, word definitions, prepositional phrases, embedded sentences, and familiar expressions) was similar across the four sets of words.

A further factor that was taken into account in matching the sets was the level of constraint imposed by each sentence frame on the words that might complete it (Schwanenflugel & Shoben 1985). It was intended that levels of sentence constraint be similar across the four sets of words, although this proved difficult to achieve. A sentence completion task was developed to explore the degree to which each sentence frame predicted the target word. This involved presenting the spoken sentence frames to five volunteers, all of whom were adult native English speakers educated to degree level. They were asked to say the word they considered most likely to complete each sentence. Responses were then collated to identify the range of words produced in response to each item. This revealed a high level of agreement between respondents (indicated by at least three respondents producing the target word) for both of the high imageability word sets (18/20 items in the high imageability/high frequency set, and 17/20 items in the high imageability/low frequency set), a moderate level of agreement for the low imageability/high frequency set (9/20 items), and a low level of agreement for the low imageability/low frequency set (5/20 items)[25]. Some sentence frames in the two low frequency sets erroneously resulted in words that held no close semantic relationship to the target, and were therefore modified to try to increase the level of sentence constraint. For instance, the sentence frame '*The detective found a hidden...*' was intended to prime the target word *clue*, but also produced the words *weapon, treasure* and *entrance*. This item was therefore changed to '*The detective found a vital ...*'. The modified sets of sentence frames were presented for sentence completion to a further five volunteers (again adult native English speakers educated to degree level). These modifications increased agreement for the low imageability/high frequency set to 14/20 items, and for the low imageability/low frequency set to 10/20. Where responses differed from the target word, there was a tendency for respondents to produce more familiar synonyms or coordinates. For instance, for the sentence frame '*The soldier received a medal for...*', four respondents said *bravery* and one said *gallantry* instead of the target *valour*. Since these responses were semantically similar to the target, this indicated that the sentence frame had primed the target semantic field. It was considered unlikely that further modifications to these sentence frames would reliably constrain responses to the target words, therefore these modified sets of sentence frames were accepted for use in testing. The

[25] It is possible that levels of sentence constraint may have been influenced by the imageability of key words in the sentence frames. Low imageability target words were more often associated with low imageability words in the sentence frame, given the abstract nature of the meanings to be primed. Thus an effect of imageability on recognition of the target word might have been compounded by an effect of imageability on processing of the sentence frame. This factor should as far as possible be controlled for if a similar task were to be used in future research.

complete list of items is given in Appendix 9 (including pronunciations) for the simple lexical decision task and in Appendix 10 for the sentence task.

Speech stimuli were digitally recorded on to DAT audio-tape in an anechoic room and acquired digitally to a PC with a sampling rate of 44100 Hz. The same female voice was recorded for all items, and used Standard British English pronunciation. Five tokens of each item were recorded, and the optimum token among these five recorded tokens was perceptually identified. The onset, duration and offset of each of these optimum tokens were accurately identified using a visual representation of the sound wave on the computer screen. This portion of the sound wave was then cut and saved as an individual .WAV format sound file.

Procedure

Participants heard each item in turn and were asked to judge whether that item was a 'real word' or a 'made up word' in the simple task, or whether the last item in the sentence was a 'real word' or a 'made up word' in the sentence task. Items within each task were presented in two blocks (A and B) on two separate testing sessions. Each block was balanced for lexicality, and words within the block were balanced for frequency and imageability. Word and corresponding nonword items did not occur in the same block. (Nonwords in Block A corresponded to words in Block B, while nonwords in Block B corresponded to words in Block A). The order of block presentation was reversed between the simple and sentence lexical decision tasks.

This experiment was set up and run using Superlab Pro 2.0 software (Cedrus Corporation 1999), a programme for designing and running psychological experiments. Stimulus presentation during experimental testing was carried out free-field using a Dell Latitude portable computer connected to an external loud speaker. Volume was set to a comfortable listening level for each participant. Testing was carried out in a quiet (though not sound-proofed) room.

A digital response box was designed especially for use in this set of experiments. The box has three buttons positioned in a left-to-right array. The centre button is coloured red, and is designated the 'Go' button. Activation of this button controls stimulus presentation. The left and right hand buttons are coloured green, and are designated the response buttons. Responses were made by pressing one of the two response buttons. These buttons were labelled:

☑	☒
yes	**no**

A response must be made following each stimulus before the experiment will proceed to the next stimulus. Superlab Pro 2.0 records which button is depressed for each stimulus item, whether that response is correct, and the time in milliseconds from the offset of the stimulus until the onset of the response. Response times were measured to within at least one millisecond accuracy using a Microsoft Multimedia Timer linked to a National Instruments DIO-24 input/output card.

Presentation of each stimulus was controlled by the participant pressing the 'Go' button on the response box. This ensured that the pace of stimulus presentation was optimised for each individual, and reduced the possibility of errors due to inattention. It also allowed for participants to take a break during testing if they were experiencing fatigue or difficulty in maintaining concentration (both factors that commonly influence performance on tasks involving language processing in participants with aphasia). Stimulus presentation was delayed by 100 milliseconds following activation of the 'Go' button, both to avoid inattention to the stimulus through attention to the action of pressing the 'Go' button, and to ensure that the click heard when the 'Go' button was depressed did not interfere with perception of the stimulus onset.

Stimuli were presented in the synchronous mode. This determined that the timer only started looking for a response at the offset of each stimulus presentation. The synchronous mode was used because this allowed for the most direct comparisons to be drawn between the same target items when they were embedded in contexts of different durations. (Within this experiment, the same lexical decision items are presented in isolation in one test, but at the end of a sentence in another test). If the asynchronous mode had been used (allowing responses to be recorded from the onset of the stimulus), it would have been difficult to directly compare response times to items across the two conditions due to the different stimulus durations. A disadvantage of presentation in the synchronous mode, however, is that all responses made before the stimulus presentation is complete are recorded with a value of zero rather than differentiating between them.

Statistical analysis

Data sets for each test included accuracy and reaction time for each case (a single presentation of a test item), grouped by participant. A small number of cases were deleted from the data since the participant accidentally pressed the 'go' button twice[26], although in most data sets there were no accidental 'go' responses. Cases where reaction times were extreme values[27] were also filtered out before statistical analysis of reaction times, in order to remove cases where the participant may not have been attending to the stimulus or where their attention was distracted before making a response. Extreme values were defined as values that fell more than two Standard Deviations above the mean reaction time for each participant on each test[28].

Statistical analysis was carried out on the prepared data sets using the SPSS version 8.0 statistical software package (SPSS Incorporated 1989). Levels of significance of $p < .05$ were taken to indicate a significant result, and $p < .005$ to indicate a highly significant result. Data from the control participants were analysed for the whole

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[26] Unfortunately it is not possible within Superlab Pro 2.0 to prevent the recording of accidental 'go' responses.

[27] The same filtering procedure was applied to both control and aphasic groups' data to ensure that valid comparisons might be made between the two groups. It should be noted however, that unlike aphasic data, control data contained few extreme reaction times.

[28] Filtering was carried out individually, rather than for the group as a whole, because there were individual differences between participants in overall response patterns, with some participants generally having slower responses than other participants. Had the data been filtered for the group as a whole, a disproportionate number of responses would have been excluded from the results of the slower responders thus creating a data set that was not representative of the whole group.

group, with *participant* defined as a random factor. This allowed the control data to provide information about the range of individual performance patterns within the group, as well as an indication of normal performance overall. Data were analysed separately for each aphasic participant, since their varying patterns of language processing impairment (summarised in Chapter 3) indicated that it would be inappropriate to treat them *a priori* as a homogeneous group. However, in some instances where patterns of performance between aphasic individuals showed strong similarities, group analyses were also carried out with *participant* defined as a random factor to explore group effects whilst taking account of individual variation.

The decision to treat the aphasic and control data differently, although it could be criticised, is considered justified on the following grounds. Firstly, in considering the accuracy data, there are clear differences between the control and aphasic groups. While controls performed very similarly to each other and were close to the ceiling of all tests, the aphasic participants showed very different patterns of accuracy across tests. Since interpretation of aphasic accuracy data requires reference to individual language processing profiles, it was considered appropriate to analyse aphasic data in detail for individuals rather than only for the group. Secondly, in considering reaction time data, it was anticipated that the aphasic participants would be much more variable than the controls. As discussed by Tyler (1992b p.278-9), aphasic participants tend not only to respond more slowly than controls across a wide range of tasks, but also to be more variable in their response speed. This proved to be the case here. For instance, on simple lexical decision there were much wider distributions of reaction times in the aphasic than the control group:

aphasic mean = 1081 ms	N= 387	SD = 964	variance = 929987
control mean = 383 ms	N = 781	SD = 195	variance = 38106

The variance in the two groups was compared using Levene's test of equality of error variances, which showed that the difference in variance is highly significant (Levene p=.000). Even when the raw reaction times were transformed into their log10 values to reduce the variance, the difference between the two groups remained highly significant (Levene p =.000). This difference in variance between the two groups meant that direct comparisons of aphasic and control group reaction time data could not be carried out, since the combined group data did not meet the assumptions of ANOVA. Indeed, when group ANOVA was attempted, the variability in the aphasic group was found to increase the error term to such a degree that even highly significant effects (e.g. of word frequency) in the control group were wiped out when the aphasic group don't show the same effect. It is unfortunate that direct group comparisons were not possible, but group analysis of control data has similarly been combined with individual analyses of aphasic data in other studies of auditory processing (e.g. Tyler 1992b pp. 278-9).

Simple Lexical Decision Results

Overall the control group made fewer errors and showed less variation in accuracy than the aphasic group on this task (control group mean accuracy = 97% SD .172; aphasic group mean accuracy = 89% SD.318; ANOVA $p < .001$**). While on average the aphasic group responded more slowly than the controls, this was not true for all the individual aphasic participants. While four of the aphasic participants had overall slower mean reaction times than the control group, JWh's reaction times fall within the normal range. This is commensurate with the results on an auditory lexical decision task reported by Tyler, Ostrin, Cooke & Moss (1995 pp.141-44). These authors tested a group of thirteen controls aged 64-77 years, and four aphasic participants. Overall, the control group's mean reaction time was 872 milliseconds (range 645-1108 ms). From the data presented it can be calculated that the aphasic participants had mean reaction times of 857 ms (DE), 916 ms (JG), 1274 ms (PK) and 1005 ms (FB)[29], thus for at least two of them reaction times appeared similar to controls. Although no statistical comparisons are presented of overall reaction times between control and aphasic participants in that study, it appears that two of the aphasic group had reaction times that were similar to the controls, while two had on average slower reaction times.

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[29] Mean raw reaction times are probably higher than those stated, since prior to analysis the authors cleaned the data by replacing all reaction times more than 2 SDs above the mean with the mean reaction time.

Lexicality

It is well established in the literature that words are responded to faster than nonwords in lexical decision, and it has been proposed that the word recognition system must carry out a more exhaustive search of the lexicon to reliably reject a nonword than to recognise a word (e.g. Coltheart et al. 1977; Tyler, Voice, & Moss 1996). Previous findings have been replicated here. The control group showed a highly significant effect of lexicality on speed of response (see Table 10), with faster responses to words than to nonwords (ANOVA p = .001**). There was a highly significant effect of participant (ANOVA p = .003**) and also a highly significant interaction between lexicality and participant (ANOVA p <.001**).

	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
non word (n=80)	505	449	648	462	455	312	690	353	419	548
word (n=80)	360	446	476	322	365	281	473	284	382	433

Table 10. Effect of lexicality on mean reaction times (ms) in simple lexical decision by control participants

The interaction between lexicality and participant was explored further. Individual patterns revealed that nine of the ten controls responded faster to words, with only DB responding faster to nonwords. It therefore appeared that the interaction between lexicality and participant may have resulted from DB's atypical pattern of reaction times. To test this hypothesis the analysis of variance was repeated excluding DB's data from the control group. However, the interaction between lexicality and participant remained highly significant (ANOVA p <.001**) indicating that it was not due to the difference between DB and the other controls.

Another possible explanation could have been that the interaction resulted from the large differences between participants in their overall speed of processing. Under this account, proportional differences in the speed of processing of words and nonwords (e.g. if words were processed 20% faster than nonwords) would result in greater differences in mean reaction times for those controls who were slower responders overall. To test this, the raw reaction times for the whole group were transformed into their log 10 values to reduce the degree of overall difference in reaction time values between participants. The analysis was carried out on these log reaction times (again excluding DB's data) to find out whether the interaction would disappear. However, this analysis produced almost identical results to analysis of raw reaction times. There were highly significant effects of lexicality (ANOVA $p < .001$**) and participant (ANOVA $p = .002$**), and a highly significant interaction between lexicality and participant (ANOVA $p = .003$**).

It was therefore concluded that the interaction must have arisen from the degree to which controls responded faster to words than nonwords. For instance, MC responded more than 200 milliseconds faster to words, while for JS the word advantage was only about 30 milliseconds. This raises an interesting point; normal listeners differ in the degree to which lexicality influences speed of processing, with one of the controls having shown no advantage at all for words. Therefore, some differences between aphasic participants, or between aphasic and control participants, might reflect this normal variation.

Given the widely accepted processing advantage for words over nonwords, it was expected that aphasic participants would similarly show a lexical advantage. This was mainly the case (see Table 11). AL and TDS responded significantly more accurately to words than nonwords, and TVR also responded more accurately to words, with the difference falling short of significance. When data were analysed for the whole group, accuracy was significantly greater for words (Chi square $p = .002$**). Interestingly, JW's overall accuracy was well within the range of the aphasic group, suggesting that his word recognition was not severely impaired by his high frequency hearing loss. All the aphasic participants except for TVR had faster mean reaction times to words. This difference was only significant for TDS, and fell just short of significance for JW. The aphasic group as a whole showed no effect of lexicality on reaction times, but a highly significant interaction between lexicality and participant (ANOVA $p < .001$**). This may in part reflect the control results, where individual differences were also found between participants in the degree to which lexicality speeded responses.

Lexicality	AL		JW		JWh		TDS		TVR	
	A	RT	A	RT	A	RT	A	RT	A	RT
nonword (n=80)	70% (n=79) [30]	1857	89%	1173	100%	495	78% (n=79)	2290	89%	1047
word (n=80)	86%	1695	91%	884	91%	423	95%	1206	96%	1133
Sig.	* .013	.432	.598	.054	* .007	.170	** .001	** .000	.072	.271

Table 11. Effect of lexicality on accuracy (Chi square) and reaction times (ms) (ANOVA) in simple lexical decision by aphasic participants

There are at least two possible accounts for the aphasic participants' greater accuracy in responding to words. These relate to these participants' impaired sublexical processing of auditory input, resulting in inaccurate or impoverished phonological representations being available to the lexical processing system. The lexical advantage may reflect a strategic effect (a bias to guess 'word' when uncertain) that arises when phonological representations are ambiguous, or alternatively, it may reflect reduced thresholds for lexical selection. The latter hypothesis was suggested by Milberg, Blumstein & Dworetsky (1988) to account for their finding that Wernicke's aphasics showed priming effects from words distorted by two phonetic features. The data do not distinguish between these hypotheses.

A somewhat surprising result was that JWh showed a reverse lexicality effect in her accuracy, making errors only on words. It may be that JWh also shows a strategic effect when her phonological representations are ambiguous, but with a bias to respond 'nonword'. Alternatively, she may have raised thresholds for selecting lexical representations as suggested by Milberg et al (1988) to account for their

[30] The maximum number of items in each set is indicated in the left-hand column of each table. Where the actual number of cases included in analysis of accuracy data differs from the maximum number (due to accidental 'go' responses), the actual number of cases is given in the relevant cell.

finding that Broca's aphasics showed no priming effects from words that were distorted by only one phonetic feature. It is interesting to note that JWh had shown a similar pattern in visual lexical decision where all her errors involved words, suggesting that patterns of lexical processing are similar across modalities. This provides support for the explanation based on raised thresholds for lexical access. JWh did not have a deficit equivalent to that in auditory processing in her sublexical visual processing, since she had no letter perception difficulties. Input to the orthographic input lexicon should not therefore be ambiguous, so the explanation based on response bias cannot apply in the same way to auditory and visual processing.

Frequency

It has been demonstrated that high frequency words are typically recognised faster than low frequency words in lexical decision tasks (e.g. Bradley & Forster 1987; Goldiamond & Hawkins 1958; Morton 1979; Whaley 1978). These findings are replicated here for the control group (see Table 12). All controls except DT responded faster to high than low frequency words (ANOVA $p < .001^{**}$). There was a highly significant effect of participant (ANOVA $p < .001^{**}$) but no interaction between frequency and participant (ANOVA $p = .671$).

Freq.	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
High (n=40)	319	415	478	266	312	248	435	261	370	413
Low (n=40)	399	476	475	376	418	314	511	308	394	453

Table 12. Effect of word frequency on reaction times (ms) in simple lexical decision by control participants

However, no aphasic participant individually, nor the group as a whole, showed any effect of word frequency on either accuracy or speed of response (see Table 13). Given the robust nature of frequency effects reported in the literature and shown by the control group here, it seemed surprising that none of the aphasic participants showed any significant effect of frequency. These results were compared with aphasic participants' performance on visual lexical decision, where frequency effects were found for only two of the aphasic participants, JWh and TVR. Although frequency was not a statistically significant factor on auditory lexical decision, the pattern is similar across the two tasks for these participants. AL's accuracy in simple auditory lexical decision appeared atypical, since he made more errors on high than low frequency words, while on visual lexical decision his errors were randomly distributed.

Frequency	**AL**		**JW**		**JWh**		**TDS**		**TVR**	
	A	RT	A	RT	A	RT	A	RT	A	RT
high (n=40)	83%	1603	90%	912	95%	404	95%	1246	98%	1090
low (n=40)	90%	1786	93%	856	88%	443	95%	1164	95%	1179
Sig.	.330	.534	.692	.772	.235	.288	1.00	.669	.556	.460

Table 13. Effect of word frequency on accuracy (Chi square) and reaction times (ms) (ANOVA) in simple lexical decision by aphasic participants

This suggests that word frequency may not determine AL's accuracy of word recognition. Furthermore, Bradley & Forster (1987) have suggested it can be harder to demonstrate frequency effects on reaction times in spoken than written word recognition, because frequency effects are detectable over a much briefer time span for auditory input. Other authors have also suggested that word frequency effects are short lived, and that they are restricted to early lexical access rather than decision stage processing (Dahan, Magnuson, & Tanenhaus 2001). Such effects may not be easily discernible in tasks such as lexical decision that require relatively late responses, particularly with long latencies as found in the aphasic data. It is also possible that a subtle effect of frequency on aphasic reaction times may have been obscured by the range and variability in their data (group range: 423-2304 milliseconds, S.D. 1091). Also, Cole-Virtue, Nickels & Coltheart (2000) examined the effects of a number of psycholinguistic variables on the auditory comprehension of fifty-four aphasic listeners. Although they found that a small number of individuals did show an effect of word frequency on accuracy of response, there was no overall effect for the group, while some of the individual participants' frequency effects consisted of an advantage for low frequency words. The lack of frequency effects shown by aphasic participants in the current experiment does therefore appear consistent with the findings of some other studies.

Imageability

Imageability reflects aspects of the semantic representations of words. Any effect of imageability on lexical decision may therefore indicate that semantic representations are accessed early in the recognition process, and that these representations facilitate lexical recognition (De Groot 1989; James 1975; Tyler, Voice, & Moss 1996). Controls showed a trend towards an effect of imageability (see Table 14), but this was not statistically significant (ANOVA p = .072). Within the group there was no consistent pattern; four participants had lower mean RTs to high imageability words, two had lower mean RTs to low imageability words and four showed virtually no difference in means. There was a highly significant effect of participant (ANOVA p <.001**), but no interaction between imageability and participant (ANOVA p = .620).

Im	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
High (n=40)	353	398	475	332	364	256	481	249	364	429
Low (n=40)	367	492	478	312	367	304	465	319	400	437

Table 14. Effect of imageability on reaction times (ms) in simple lexical decision by control participants

Although all but JW achieved higher scores for high than low imageability words, no aphasic participant showed a significant effect of imageability on their accuracy of response to words (see Table 15). AL showed an influence of imageability on speed of response with faster responses to high imageability words, but this fell just short of statistical significance. The aphasic group as a whole showed no effect of imageability on either accuracy or reaction times.

Reports that highly imageable or concrete words are recognised more quickly than abstract words in lexical decision have not been replicated in this study, since neither control nor aphasic groups showed an overall effect of imageability on reaction times to lexical decisions. There did not even appear to be an underlying trend towards a facilitatory effect of imageability, since there was no consistent pattern to the control group results.

Imageability	AL		JW		JWh		TDS		TVR	
	A	RT	A	RT	A	RT	A	RT	A	RT
high (n=40)	90%	1412	90%	907	95%	384	98%	1121	98%	1125
low (n=40)	83%	1977	93%	861	88%	465	93%	1206	95%	1142
Sig.	.330	.052	.692	.806	.235	.288	.305	.366	.556	.888

Table 15. Effect of imageability on accuracy (Chi square) and reaction times (ms) (ANOVA) in simple lexical decision by aphasic participants

The methodology of this experiment was compared with that of Tyler, Voice & Moss (1996) to identify whether the difference in findings could be due to any procedural variation. One key difference found was that Tyler et al had controlled their word stimuli for cohort size. They reported significantly faster reactions to high imageability words only for those words that had large phonological neighbourhoods. The words selected for the experiment reported here were not controlled for neighbourhood density. Data exploration was therefore carried out to identify whether the imageability stimulus sets might be poorly balanced for neighbourhood size[31]. It was found that for the high frequency words there was a weakly significant relationship between imageability and neighbourhood size (ANOVA $p = .040^*$), with high imageability words having on average larger neighbourhoods than low imageability words. The mean neighbourhood was 6.8 for high imageability words and 3 for low imageability words. For low frequency words there was no significant relationship between imageability and neighbourhood size.

Further analyses were carried out to investigate whether reaction times for the control group were related to neighbourhood size (Luce, Pisoni, & Goldinger 1990). For the whole set of words, a highly significant positive correlation was found between neighbourhood size and reaction time (Pearson correlation coefficient = .224**, 2-tailed significance $p < .001$). This resulted from participants responding faster to words that had smaller neighbourhoods. Since the set of high imageability words overall had larger neighbourhoods than the set of low imageability words (at least among the high frequency items), it follows that the inhibitory effect of a large cohort would disproportionately affect words in the high imageability set. The effect of this inhibition may have overridden any facilitation that imageability could have had on controls' speed of processing.

To test this hypothesis, the effects of imageability and neighbourhood size on reaction times were analysed separately for the high frequency and low frequency sets of words. This revealed that for the high frequency word set, there was no effect of imageability (ANOVA $p = .779$). There was a highly significant effect of participant (ANOVA $p = .001^{**}$) and no interaction between imageability and

---

[31] Neighbourhood density values were kindly provided by Professor David Howard, University of Newcastle. Values refer to the number of different words in the CELEX database that have identical numbers of syllables and phonemes, and that differ by just one phoneme. Words with one pronunciation are counted once, so for example *talk* has only one neighbour from *walk*, even though CELEX lists it twice as both a verb and a noun.

participant (ANOVA p = .724). The high frequency word set showed a highly significant positive correlation between reaction time and neighbourhood density (Pearson correlation coefficient = .196**, p <.001). For the low frequency word set there was a significant effect of imageability, with faster reactions to high imageability words (ANOVA p = .019*). There was a highly significant effect of participant (ANOVA p = .003**) and no interaction between imageability and participant (ANOVA p = .683). The low frequency word set also showed a highly significant positive correlation between reaction time and neighbourhood density (Pearson correlation coefficient = .227**, p <.001). These results are consistent with the argument that, for the high frequency items, the inhibitory effect of the denser phonological neighbourhoods of the high imageability words counteracted the expected facilitatory effect of imageability. The facilitatory effect of imageability is revealed when reaction times are analysed only for the low frequency items, since imageability is not confounded with neighborhood size in this set.

The results for aphasic participants do perhaps indicate a stronger influence of imageability than found for the controls. None of the aphasic participants individually, nor the group as a whole, showed a significant overall effect of imageability on accuracy in simple lexical decision. However, AL, JWh, TDS and TVR all made more errors on low than high imageability words. The aphasic group data was therefore analysed separately for high and low frequency word sets, to determine whether the confounding of neighbourhood density with imageability in the high frequency set. As expected, this revealed no effect of imageability on accuracy for the high frequency words, but a significant effect for the low frequency words (Chi square p =.009**). This suggests that, as with the control group, a neighbourhood density effect may have masked an imageability effect when all the items were included in the analysis. This claim is supported by evidence that word imageability influences auditory processing in these participants' language profiles, since AL, JWh, TDS and TVR had all shown clear imageability effects on auditory synonym judgement. A possible explanation for the relatively weak influence of imageability on their lexical decision accuracy is that the nature of the synonym judgment and lexical decision tasks is very different. In lexical decision the participant is only required to process one word/nonword at a time, whereas in synonym judgement each item consists of two words. Also, the nature of the decision required is less complex in lexical decision (simple recognition) than in synonym judgement (generating a semantic representation for each word, and judging the relatedness of the two representations). It is not surprising that the more complex task, synonym judgement, should produce more errors and so show a much stronger effect of imageability.

It is interesting that JW was the only aphasic participant who made more errors on high imageability words in simple lexical decision. JW had shown no effect of imageability on visual lexical decision, and was also the only participant not to show an imageability effect in auditory synonym judgement. This was despite the fact that he made close semantic errors on both spoken and written word to picture matching, indicating difficulty in accessing precise semantic representations. The lack of any effect of imageability on tasks such as auditory lexical decision may indicate that, without a picture or other context to support his semantic access, JW is often unable to generate sufficient semantic activation from spoken words for imageability to have any effect on his lexical processing. This hypothesis will be considered further in experiments two and three, in relation to differences between word and picture contexts in JW's phoneme discrimination.

Analysis of reaction times showed that only AL responded faster to high than low imageability words, with this difference almost reaching significance. Pearson correlations were carried out to determine whether the inhibitory effect of neighbourhood density may have interfered with semantic facilitation of processing speed for the aphasic participants, as was suggested for the control group. When all words were included in the analysis, JW and TDS showed a significant positive correlation between reaction time and neighbourhood density. (For JW Pearson Correlation = .245*, 2-tailed significance = .030; For TDS Pearson Correlation = .239*, 2-tailed significance = .035). TVR also showed a significant positive correlation, but only for low frequency words (Pearson Correlation = .370*, 2-tailed significance = .020). Neither AL nor JWh showed any significant correlation between reaction time and neighbourhood density, although as discussed previously, this may be due to variability in overall reaction times. These results demonstrate that, at least for three of the aphasic participants, words that have many phonological neighbours are recognised more slowly than words with few neighbours. As discussed in relation to controls' results, this inhibition would disproportionately affect the high imageability items and so may mask a weak facilitatory effect of imageability on reaction times.

Sentence Lexical Decision Results

The simple lexical decision stimuli were presented following predictive sentence contexts . The three experimental factors of lexicality, frequency and imageability were analysed as for simple lexical decision, and in addition, the effects of these factors were compared between simple and sentence lexical decision tasks[32].

On the sentence lexical decision task the control group's mean score was 99% (range = 98-99% raw score range = 156/160-159/160 SD = .117). The aphasic group mean score was 89% (range = 82-96% raw score range = 130/159 – 153/160 SD = .308). The difference in accuracy between control and aphasic groups was highly significant (chi square $p <.001$**).

Overall, controls responded more accurately (logistic regression $p =.001$**) and faster (repeated measures $p <.001$**) to items in the sentence than the simple lexical decision task. Three of the aphasic participants similarly responded faster when items followed a sentence context (repeated measures: JW $p <.001$**; TDS $p = .011$*; TVR $p <.001$**). In contrast JWh responded faster to items presented in simple lexical decision (repeated measures $p = .010$*). Overall accuracy was slightly higher in sentence lexical decision for four of the aphasic participants, but this difference was not significant for any of them (logistic regression $p > .250$).

[32] Comparisons between the two tasks were carried out with Binary Logistic Regression using the Forward Likelihood Ratio method for accuracy data, and using Repeated Measures ANOVA for reaction times.

Lexicality

There was no effect of lexicality on reaction times for the control group (ANOVA p = .628) (see Table 16). There was a highly significant effect of participant (ANOVA p <.001**), but no interaction between lexicality and participant (ANOVA p = .110). The lack of an effect of lexicality on sentence lexical decision was significantly different to the results on simple lexical decision, where controls had responded faster to words (repeated measures p <.001**).

	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
Nwd (n=80)	338	586	466	353	339	243	437	172	260	412
Word (n=80)	337	606	457	316	344	209	446	165	323	343

Table 16. Effect of lexicality on reaction times (ms) in sentence lexical decision by control participants

It is interesting that the effect of lexicality should be so strikingly different for the control group across the two tasks. One possible cause of the lack of a lexicality effect in sentence lexical decision that was considered was that there might have been greater variability in overall reaction times on this task than on simple lexical decision. Under this argument, the variance due to factors associated with sentence processing might be large enough to mask the effect of lexicality. As the sentence stimuli are of varying lengths and syntactic forms, with a variety of intra-lexical relationship types and verb argument structures, it is possible that they would require different amounts of time to process. This hypothesis was tested by examining the control group's overall variance in reaction times across the two tasks. Although responses were faster overall on sentence lexical decision, there was almost no difference in variance between the two tasks. On simple lexical decision the standard deviation was 216 (mean 432 milliseconds), while on sentence lexical decision it was 211 (mean 358 milliseconds). This indicates that the lack of a demonstrable lexicality effect is not due to greater variability in the sentence lexical decision data but must relate to some other factor/s.

Another possibility considered was that decision making in the sentence lexical decision task may rely more heavily on the integration of representations of the constituent words than on simple lexical access. A number of studies have demonstrated that sentence contexts facilitate lexical decisions for words that are congruent with the context, and inhibit decisions for incongruous words (e.g. Fischler & Bloom 1979; Swinney 1979). It has been argued that the slowing of responses to incongruous words reflects the increased time spent attempting to integrate representations of these words with their preceding contexts. Although ostensibly the sentence lexical decision task can be carried out purely on the basis of the lexical status of the final word/nonword, it may be that participants make their decision based on how well this final item 'fits' with the preceding context. Indeed, there is evidence in the literature that normal participants attempt to integrate syntactic and semantic representations when processing sentences even when the task does not explicitly require this (Fischler & Bloom 1979). If the sentence lexical decision task really relied on post-lexical integration processes, then the rejection of nonwords might be based as much on their lack of fit with the expectancy set generated by the preceding context as on the fact that they are not recognised as words. Were that the case, it would be predicted that latencies for nonwords, just as for incongruous words, would be slower than responses to congruent words. However, controls' latencies for nonword responses in the sentence lexical decision task here are no slower than latencies for words, seeming to undermine the suggestion that nonwords are rejected on the basis of the difficulty in integrating them with the sentence context. It would appear that decisions to both nonwords and words are made at a similar point in time, presumably at the offset of lexical search processing.

This issue might be clarified through data of a different type. Reaction times are accepted as providing reasonably reliable indicators of the priming effects that result from the spread of activation from one word to another. However, in studies that have utilized both reaction time and event related potential data, complex priming effects that rely on the integration of a number of levels of representation have been more reliably demonstrated by modulation of the N400 event related potential (Chwilla, Kolk, & Mulder 2000). Event related potential data are obtained by measuring voltage fluctuations that are related to stimulus presentation in scalp recorded electroencephologramms. These voltage fluctuations may be positive (P) or negative (N), and are measured from the time of stimulus onset until the fluctuation peak. Thus the N400 event related potential is a negative peak that occurs approximately 400 milliseconds after a stimulus. This particular event related potential is of interest, because it has been established that it relates to the semantic processing of words. The N400 has a greater amplitude when a word is preceded by an unrelated than a related word, or when the expectancy set generated by a preceding sentence fragment is large (see Chwilla et al p. 317-8 for a review of relevant studies). The authors argue that the N400 event related potential reflects the ease with which a word can be integrated with it's preceding context, whether that context is provided by a word or a sentence fragment. The more easily a word can be integrated with the representation of the context, the smaller the amplitude of the N400 potential. If the decision to reject a nonword in the sentence lexical decision task in this study were based on non-congruence with the syntactic and semantic representations generated by the sentence frame, the lexicality effect should be discernible through increased N400 amplitudes for nonword trials compared to word trials. Future research might seek to resolve this issue.

In contrast to the control group, aphasic participants were strongly influenced by lexicality in sentence lexical decision (see Table 17).

Lexicality	AL		JW		JWh		TDS		TVR	
	A	RT	A	RT	A	RT	A	RT	A	RT
nonword (n=80)	71% (n=79)	1984	88% (n=40)	565	93%	550	73% (n=79)	2544	88%	843
word (n=80)	93%	1981	98% (n=40)	600	99%	546	99%	1777	98%	971
Sig.	** .000	.993	.090	.475	.053	.953	** .000	** .001	* .016	* .024

Table 17. Effect of lexicality on accuracy (Chi square) and reaction times (ms) (ANOVA) in sentence lexical decision by aphasic participants

All of the aphasic participants responded more accurately to words than to nonwords. This difference was highly significant for AL and TDS, significant for TVR, and just short of significance for JW[33] and JWh. The degree of lexical advantage was compared between the two lexical decision tasks. The ratio of percentage correct responses for nonwords to words showed that the degree of lexical advantage was greater in sentence lexical decision for all five participants (see Figure 5). The difference between the two tasks in degree of lexical advantage for accuracy was highly significant for TDS (logistic regression p <.001**), and significant for AL (logistic regression p = .013*).

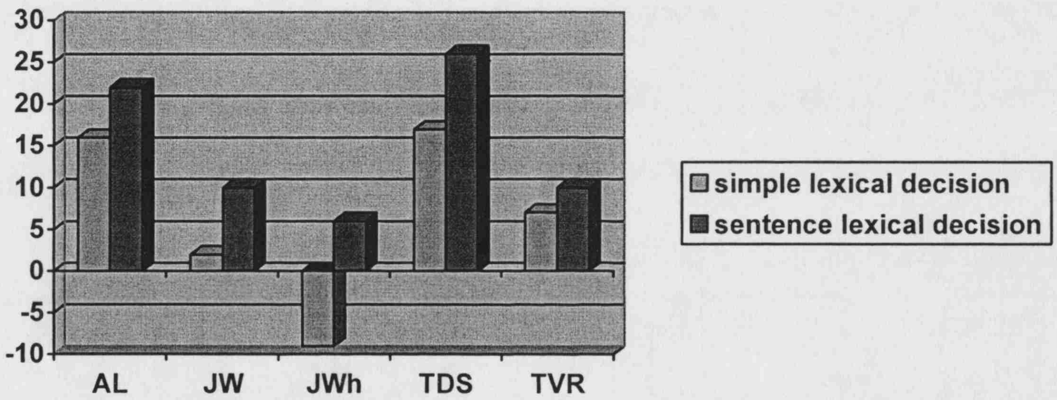

Figure 5. Comparison of size of lexical advantage (expressed as percentage difference between nonword and word accuracy scores) between simple and sentence lexical decision tasks for aphasic participants.

Both TDS and TVR showed a significant effect of lexicality on speed of response in sentence lexical decision. However, their directions of effect were different; TDS responded faster to words, while TVR responded faster to nonwords. The effect of lexicality on reaction times was compared between the two tasks. Repeated

[33] JW's data is based on only 80 of the total 160 items (40 words and 40 nonwords). Unfortunately one of his data files related to this task was lost, probably during transfer from one lap top computer to another. Attempts were made to retrieve the lost data once this error was discovered, but without success. This is why the difference in JW's accuracy between words and nonwords, although apparently the same as that shown by TVR, does not achieve significance.

measures tests revealed no differences in the effect between simple and sentence lexical decision for four of the aphasic participants. Only JW showed a trend towards a difference in effect (repeated measures p =.074), reflecting the fact that his responses were faster for words in simple lexical decision, but showed no difference between word and nonword latencies in sentence lexical decision.

The same reasons that were suggested to account for the lexical advantage in accuracy for some of the aphasic participants in simple lexical decision are relevant here. These were either that the lexical advantage reflected a bias to respond 'word' when phonological representations were insufficient to drive lexical selection, or that participants have reduced thresholds for lexical access associated with their impoverished phonological encoding. However, the degree of lexical advantage is even greater in sentence lexical decision than in simple lexical decision. This is most dramatic for JWh; she no longer shows an advantage for nonwords, but like the other aphasic participants responds more accurately to words in sentence lexical decision. It has been argued by a number of authors that a clear semantic context can make the meanings of related or congruent words available prior to those words being recognised (e.g. Swinney 1979; Zwitserlood 1989). Moss & Gaskell (1999 p.73) suggested that this early activation of semantic representations allows the semantic properties of an incoming word to be rapidly evaluated against the prior context. This speeds recognition of highly congruent words, and so provides an efficient mechanism for rapid processing of connected speech.

The aphasic participants in this study might be particularly sensitive to contextually generated semantic activation, due to their impairment in the mapping of sound onto meaning. (The nature of the impairment varies between individuals, see chapter three). Since they might not reliably access meanings on the basis of information flow from the acoustic signal, the effects of contextually activated semantic representations may be greater than for normal listeners, whose semantic access will be more strongly driven by reliable bottom-up processing. It is plausible that this would result in a stronger effect of lexicality in the context of a sentence for aphasic listeners than controls, with nonwords being mistaken for similar-sounding words that fit well with the context. This hypothesis was tested by comparing the effects of neighbourhood density across the two tasks, since this is a measure related to phonological word forms. For those participants whose reaction times had been faster to words with small neighbourhoods in simple lexical decision (JW and TDS), neither showed any effect of neighbourhood size on reaction times in sentence lexical decision. This difference may indicate greater reliance on phonological representations in simple lexical decision, and greater reliance on other levels of representation (such as contextual semantics) in the sentence task. The other participants showed no overall effect of neighbourhood density on either task. Interestingly, it will be shown in chapter five that JW and TDS differ from the other aphasic participants in some important respects. These two participants showed much poorer discrimination of different word pairs than the others, and were the only individuals to show statistically significant phonological encoding difficulties for words. Such an encoding difficulty may be expected to disrupt access to lexical and semantic representations of spoken words, thus increasing reliance on contextual sources of information. This claim is supported by evidence related to effects of contrast position in picture-word verification that will be presented in chapter six, that suggests both JW and TDS make judgements primarily at the semantic level when provided with a picture context.

Frequency

Although eight of the controls had lower mean reaction times to high than to low frequency words (see Table 18), this difference was not significant (ANOVA p = .100). There was a highly significant effect of participant (ANOVA p <.001**), but no interaction between participant and frequency.

Freq	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
High (n=40)	332	566	484	302	328	192	422	159	318	344
Low (n=40)	341	648	432	330	362	226	470	170	330	343

Table 18. Effect of word frequency on reaction times (ms) in sentence lexical decision by control participants

The effect of word frequency was significantly different for controls across the two lexical decision tasks (repeated measures p = .024*). This difference is related to the degree to which frequency speeds word recognition, with greater facilitation in simple lexical decision, rather than to any difference in the direction of effect. It should be noted that eight of the ten controls did have lower mean reaction times to high frequency words in sentence lexical decision; although not statistically significant, this similarity to the direction of effect found on simple lexical decision may suggest that a subtle facilitatory effect of word frequency exists but is masked by other processing factors for the sentences. The difference in the size of the effect cannot, however, be due to greater variability in the sentence lexical decision data, since variance has already been shown to be almost identical in the two tasks.

Although JW, JWh, TDS and TVR all made more errors on low than high frequency words, these differences were not significant either for individuals or for the group (see Table 19).

Frequency	AL		JW		JWh		TDS		TVR	
	A	RT	A	RT	A	RT	A	RT	A	RT
high (n=40)	88%	1792	100% (n=20)	606	100%	535	100%	1619	100%	887
low (n=40)	98%	2161	95% (n=20)	594	98%	559	98%	1935	95%	1058
Sig.	.090	.395	.311	.860	.314	.795	.314	.269	.152	* .031

Table 19. Effect of frequency on accuracy (Chi square) and reaction times (ms) (ANOVA) in sentence lexical decision by aphasic participants

The lack of a clear frequency effect on accuracy of aphasic responses may be due to a ceiling effect, as suggested in relation to simple lexical decision, since JW, JWh, TDS and TVR all scored 100% on the high frequency words and 95-98% on the low frequency words. It is suggested that the effects of frequency on both lexical decision tasks, although inconclusive, are at least congruent with a predicted advantage for high frequency words for these four participants. It is interesting that AL differed from the other aphasic participants in that he made more errors on high frequency words. However, this effect was not significant and it was suggested earlier that AL's accuracy of word recognition is not strongly influenced by word frequency. Only AL and TDS showed a significant difference in the effect of frequency across the two tasks (logistic regression: for AL $p = .019*$; for TDS $p < .001**$).

TVR showed a significant effect of frequency on his reaction times in sentence lexical decision, with faster responses to high than to low frequency words. AL, JWh and TDS also had faster mean reaction times for high frequency words, but for them the difference was not significant. When results were analysed for the group, there was a trend towards an effect of frequency on reaction times (ANOVA $p = .076$). There was no difference in the effect of frequency on reaction times for any individual aphasic participants, nor for the group, when results were compared between simple and sentence lexical decision tests (repeated measures $p > .190$).

Imageability

The control group showed a weakly significant effect of imageability on reaction times (ANOVA $p = .032*$) (see Table 20). Interestingly, this difference arose from a tendency towards faster responses to low than to high imageability words. There was a highly significant effect of participant (ANOVA $p < .001**$), but no interaction between participant and imageability (ANOVA $p = .973$). The effect of imageability was significantly different across the two lexical decision tasks for the control group (repeated measures $p = .018*$), reflecting the fact that the direction of effect was more consistent in sentence lexical decision than simple lexical decision.

Imag	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
High (n=40)	336	603	479	322	333	220	461	181	338	366
Low (n=40)	338	611	435	310	356	197	431	149	309	321

Table 20. Effect of imageability on reaction times (ms) in sentence lexical decision by control participants

To find a significant reverse imageability effect on this task was somewhat surprising. It was considered that this might be a spurious result arising from the confounding of imageability with neighbourhood density in the lexical decision stimuli. A Pearson Correlation analysis was therefore carried out to explore the relationship between reaction times and neighbourhood density in this task. Although the effect of neighbourhood density was weaker in sentence lexical decision than simple lexical decision, controls again showed a tendency to respond faster to words with few phonological neighbours. There was an almost significant positive correlation between reaction times and neighbourhood density, although only for the high frequency words (Pearson correlation = .097, 2-tailed significance = .056). As discussed previously, neighbourhood density is inversely related to imageability within the high frequency word set. Controls' responses are faster to words with smaller neighbourhoods, and these words tend to be lower in imageability than those with large neighbourhoods. The apparent reverse imageability effect for controls' reaction times in sentence lexical decision may therefore really be a neighbourhood density effect. Indeed, when the analysis was carried out just on the low frequency word set, no effect of imageability was found (ANOVA $p = .325$).

An alternative account of the reverse imageability finding could be based on the notion of expectancy sets primed by the sentence contexts (see chapter one (Becker 1980; Schwanenflugel & Shoben 1985). A spurious reverse imageability effect could have arisen had the sentence frames for the low imageability words been more highly constraining than those for the high imageability words. More highly constraining sentence contexts would produce smaller expectancy sets and less competition between lexical candidates, and so facilitate faster word recognition. However, results of the sentence completion task using the lexical decision sentence frames (see chapter two) showed much greater agreement between responses to the frames that preceded high imageability words than to those that preceded low imageability words. The facilitatory effect of the preceding context should therefore be greater for the high imageability words, and should not result in a reverse imageability effect. Thus the account of the reverse imageability effect in terms of neighbourhood density at present seems the most likely.

All of the aphasic participants performed close to the ceiling of the test, and none showed any significant effect of imageability on accuracy in sentence lexical decision (see Table 21). There was no significant difference in the effect of imageability between the two tasks for three of the aphasic group (logistic regression $p > .10$); only AL and TDS showed a difference in effect (logistic regression for AL $p = .019$*; for TDS $p < .001$**).

Imageability	AL		JW		JWh		TDS		TVR	
	A	RT	A	RT	A	RT	A	RT	A	RT
high (n=40)	95%	1978	100% (n=20)	597	100%	573	98%	1904	95%	942
low (n=40)	90%	1985	95% (n=20)	603	98%	518	100%	1656	100%	999
Sig.	.396	.987	.311	.939	.314	.554	.314	.386	.152	.479

Table 21. Effect of imageability on accuracy (Chi square) and reaction times (ms) (ANOVA) in sentence lexical decision by aphasic participants

There was no effect of imageability on any aphasic participant's reaction times, and no difference in the effect of imageability on reaction times across the two lexical decision tasks for four of the aphasic participants. Only TDS showed a trend towards a difference (repeated measures $p = .096$), which related to his slightly faster reaction times to high imageability words in simple lexical decision, and to low imageability words in sentence lexical decision. As discussed in relation to simple lexical decision, the lack of significant imageability effects for aphasic participants may be at least partly due to the confounding of imageability with neighbourhood density in the word stimuli.

General discussion

In considering the findings of this experiment, there are two methodological limitations that must be taken into account. The first relates to the selection of the word stimuli, and has been discussed above in relation to the effects of imageability. It is unfortunate that the factor of neighbourhood density was not taken into consideration in the design of the lexical decision stimuli during preparation of the PALPA test battery (from which the lexical decision tasks in this study were adapted). The fact that neighbourhood density has proved to be inversely related to imageability has certainly reduced the effectiveness of these tasks in exploring the effects of semantic factors on word recognition. More conclusive results might be obtained if the experiment were repeated using words sets balanced for frequency, imageability and neighbourhood density.

The second limitation concerns statistical treatment of the data (see chapter two). Whereas control data have been analysed for the group, aphasic data have mainly been analysed separately for each participant. This approach reflects the heterogeneity of the aphasic population and has permitted consideration of individual processing patterns in some depth. However, one important consequence is that statistical tests of aphasic data are considerably less powerful than those carried out on control group data, since only one tenth the number of cases is available for each analysis. It is therefore more difficult to show statistically significant effects of experimental factors for individual aphasic participants than for controls, which has created some difficulties in making comparisons between control and aphasic data. The approach taken has been to allow some flexibility in the interpretation of aphasic data, with theoretical discussions based at times on effects that fall short of statistical significance. The advantages of this were discussed by Tyler (1992b pp.278-279), who took a similar approach in comparing aphasic to control performance in word monitoring tasks. However, it has resulted in some of the conclusions drawn being tentative. Further research, with greater statistical power built into the single-case design, might resolve these uncertainties.

Nevertheless, this experiment has provided a number of useful findings. One of the main questions that this experiment sought to address was whether the factors that influence auditory word recognition are the same for words heard in isolation and words heard in the context of a sentence. A number of differences have been found both between the two context conditions, and between control and aphasic participants.

For items presented in isolation, controls process words more quickly than nonwords, and high frequency words more quickly than low frequency words. When the confounding effect of neighbourhood density was addressed, it was found that controls recognised high imageability words faster than low imageability words. Significant facilitatory effects of lexicality, frequency and imageability were all, however, absent when words followed a sentence context. Aphasic participants as expected showed individual variations in patterns of performance. Four of the group showed some advantage for processing words over nonwords, both when words were presented in isolation and when they followed a sentence context. One participant, JWh, showed an advantage for nonwords in isolation but an advantage for words when presented in sentences. No clear influence of word frequency was found for the aphasic participants, with the exception that TVR responded faster to high frequency words only when they followed a sentence context. Overall, aphasic participants showed no clear effects of imageability. The possibility that aphasic participants do experience some facilitation from both word frequency and imageability, but that these effects may have been masked by other factors, has been discussed above.

It is interesting to speculate as to why the effects of sentence contexts on the lexicality effect should be different for aphasic compared to control participants. One account might be related to hemispheric localisation of language functions, since it has been suggested that the two cerebral hemispheres process linguistic context differently. While both hemispheres are sensitive to priming between semantically related words, it is the left hemisphere that is particularly sensitive to the syntactic and semantic relations conveyed by sentences (Faust & Kravetz 1998). It has also been suggested that cerebral dominance for speech perception may shift from the left to the right hemisphere after onset of aphasia (see chapter one), and that some agrammatic aphasic listeners interpret sentences primarily by recognising and combining the meanings of individual words in their serial order (based on studies of event related potentials by Hagoort, Wassenaar, & Brown 2003). Since all of the aphasic participants in this study have sustained significant damage to their left hemispheres, it is possible that they would rely more heavily on right-hemisphere intra-lexical semantic priming rather than left-hemisphere dominant sentence-level priming, even when listening to sentences. This would be in keeping with the suggestion by Metz-Lutz & Dahl (1984) that their aphasic patient showed increased reliance on right-hemisphere lexical-semantic knowledge in auditory processing, evidenced by a left-ear advantage for processing verbal material in a dichotic listening task.

Consideration of performance on the two profiling assessments that used sentence stimuli may lend weight to this notion. On the Test for Reception of Grammar (Bishop 1989), all of the aphasic participants showed significant difficulties in the processing of sentence structures, yet they were able to make accurate judgements about semantic anomaly between words in sentences. The difference between control and aphasic results in effect of lexicality across the two tasks may have arisen from the aphasic participants having relatively intact intra-lexical semantic priming, in conjunction with a phonological encoding deficit (as demonstrated in the phoneme discrimination experiments that follow). This might induce a greater number of errors by aphasic listeners on nonwords that sound similar to words when they follow a predictive context. The congruent word might have its level of activation raised by the context, and inaccurate or ambiguous phonological representation of the nonword stimulus might not sufficiently suppress this active candidate. While controls would presumably also show intra-lexical priming of the congruent word, their intact phonological encoding would effectively suppress this candidate when the input was a similar sounding nonword.

To determine whether the effect of the sentence contexts in this experiment might actually reflect simple intra-lexical priming, it would have been helpful to compare the priming effects of sentence contexts with the effects of single word primes. A third lexical decision task, using single word primes, was carried out for this purpose. Due to concerns over the number and length of testing sessions required of participants, only a subset of the lexical decision items were included in the primed lexical decision task. Unfortunately this reduced the statistical power of the data too far for the results to assist in repeated measures comparisons between single word and sentence primes. The results were not therefore presented here. Further research, in which performance on simple and sentence lexical decision tasks is compared to a primed lexical decision task using the full set of lexical decision items, could provide clearer insights into the nature of sentence context effects in aphasic listeners.

The next chapter will present an experiment that further explores the processing of words and nonwords, and focuses particularly on the effects of lexical contexts on phoneme discrimination.

Chapter 5 Influences of Lexical Status on Phoneme Discrimination

Introduction

The effects of sublexical, lexical and semantic contexts on speech perception have all been described in the literature, with a number of competing theoretical models proposed to account for them (see chapter one). For instance, evidence was presented to suggest that lexical status can influence categorical boundaries between phonemes for normal listeners (e.g. Ganong 1980). It was also reported that listeners automatically activate a cohort of lexical candidates upon hearing a word, and usually select the unique target word very rapidly. One debate has focused on whether context influences the encoding of phonetic information, or whether it affects only the output of encoding processes. An experiment was designed to explore the nature of the relationship between phonological encoding and lexical context. This experiment explored the discrimination of phoneme contrasts under two types of linguistic context: nonword and word minimal pairs. The processing of a nonword does not normally result in the selection of a lexical candidate, although phonological neighbours will initially be activated during lexical search processes (Luce & Large 2001;Vitevitch et al. 1999). Presentation of contrasts in nonwords therefore limits the effects of lexical representations on phonetic decision making, and so can be considered a relatively 'pure' test of phonological encoding. This task thus provides a baseline against which to compare the results of the word discrimination task. This experiment sought to address two main questions. The first is whether the discrimination of phonetic contrasts is influenced by the lexical status of the contexts in which they are heard. If there are contextual influences on discrimination, a further question is whether these are similar for control and aphasic listeners. The effects of three experimental factors were explored in nonword and word phoneme discrimination tasks. These factors were the match between pairs of items, the syllable position of phonetic contrasts, and the type of phonetic contrast.

Method

Participants

A group of five aphasic listeners and a group of ten controls took part in the experiment. The five aphasic participants were the same individuals as profiled in chapter three (Table 1), and whose results were presented in chapter four. The ten control participants were the same group as described in chapter four (Table 7).

Stimuli

There were one hundred and twenty-eight items in each of two tests. In one test the items consisted of nonwords (Appendix 11), and in the other test they consisted of words (Appendix 12). The procedure for recording the stimuli was the same as described in chapter four in relation to the lexical decision tasks. All items were pairs of monosyllables with CVC structure. Sixty-four items in each test were minimal pairs and sixty-four items were matching pairs. Matching pairs were formed of two different tokens of each of the syllables that made up the minimal pair items. Each item in the word discrimination task was closely matched to an item in the nonword task, such that the same phonetic contrasts were presented within each task in the same syllable-positions, and adjacent to the same vowels. There were four sets of sixteen minimal pairs in each test, in which the two syllables in the pair differed in voicing, place of articulation, manner of articulation, or a combination of two of these features. In total there were equal numbers of contrasts in syllable-initial and syllable-final position. Unfortunately, it was not possible to achieve equal distribution of syllable-initial and syllable-final position contrasts across the four sets of contrast types[34]. In each of the sets of voicing and two feature contrasts, there

[34] Stimulus sets were developed to be closely matched across both nonword and word items. The words all had to be familiar and highly imageable nouns to permit their use in the picture-word verification task of experiment three, and in a further sentence judgement experiment that is not

were eight syllable-initial contrasts and eight syllable-final contrasts; in the set of place contrasts, four were syllable-initial and twelve were syllable-final; and in the set of manner contrasts, twelve were syllable-initial and four were syllable-final.

The words used in the word discrimination test had the following distributions[35]:

Familiarity	mean = 560	range = 171	SD = 47
Imageability	mean = 572	range = 182	SD = 42
Spoken Noun Frequency	mean = 39	range = 442	SD = 72

Procedure

General procedures for task presentation and recording of responses were as described in chapter four for the lexical decision experiment. In the nonword minimal pair test participants were informed that they would hear pairs of 'made up words', while in the word minimal pair discrimination test they were informed that they would hear pairs of words. Participants were instructed to press the 'go' button to initiate presentation of an item. Participants were asked to judge whether the two items in each pair were the same or different. Participants heard and responded to each item in turn. Responses were made by pressing one of the two response buttons. These buttons were labelled:

♦♦	♦O
same	**different**

---

reported in this thesis. These multiple constraints, combined with the fact that only CVC syllables were used, did not allow for even distribution of syllable position across the contrast types.

[35] The data from which these distributions were calculated were kindly provided by Professor David Howard, University of Newcastle. Ratings of familiarity and imageability were drawn from the Oxford University MRC Psycholinguistic database, while spoken word frequency counts were drawn from the CELEX database.

Within each minimal pair test, each pair was presented twice with the order of the two tokens reversed on the second occasion. An inter-stimulus interval of 750 milliseconds was inserted between the two tokens of each pair. Stimuli were presented in four blocks over two different testing sessions. Items were distributed across the four blocks such that the two presentations of each minimal pair occurred on different testing sessions, and the matching pairs corresponding to each minimal pair were not presented in the same block as the minimal pair. The order of block presentation was reversed between the nonword and word minimal pair tests.

Phoneme Discrimination in Nonwords Results

Overall accuracy for the control group was close to the ceiling of the test (mean score 98% range = 96-99% raw score range = 123/128-127/128 SD = .149). The aphasic participants all made errors in nonword discrimination, with accuracy levels below the range for the control group (aphasic mean score 85% range 79-92 % raw score range 101/127 – 116/127). The difference in overall accuracy between the two groups was highly significant (ANOVA $p < .001$**).

Effects of match and position

The nonword stimuli consisted of equal numbers of same and different pairs. Control group responses to the same and different pairs were compared (the factor of match) (see Table 22). There was no overall effect of match on reaction times (ANOVA $p = .907$), but there was a significant effect of participant (ANOVA $p = .000$**) due to differences between controls in speed of processing. There was also a significant interaction between match and participant (ANOVA $p = .028$*). This arose from differences in both the degree and the direction of the effect of match, with some participants responding faster to same pairs and others responding faster to different pairs. This finding is considered further below in relation to the effect of contrast position.

The pairs of different nonwords consisted of equal numbers of contrasts in the initial and final segments of the syllable. Controls' responses to phoneme contrasts that occur in syllable-initial position were compared to those that occur in syllable-final position (see Table 27). All controls responded faster to initial than to final contrasts (ANOVA $p < .001^{**}$). There was a highly significant effect of participant (ANOVA $p < .001^{**}$), but no interaction between participant and position ($p = .350$). The fact that temporal aspects of the acoustic signal are reflected in controls' response times suggests that the same-different decision is being made on the basis of representations that maintain temporal information. This is unsurprising in relation to the processing of nonwords (for which we assume only phonetic or phonological representations to be available) but will be compared below to patterns on word discrimination, in which decisions could potentially be made at higher levels of representation. It also suggests that the same-different judgement is made on the different-pairs as soon as a phonetic difference is detected, with responses to initial contrasts often preceding the offset of the second syllable (and so being recorded as a reaction time of 0 milliseconds).

One possibility considered was whether the lack of any clear effect of match might have arisen from an interaction between the effects of match and position. It was predicted that responses to different pairs should be faster than responses to same pairs, at least for pairs that differed on the initial segment. This is because participants should be able to detect the contrast prior to the offset of the second syllable. The effect of match was therefore analysed separately for initial and final contrasts.

	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
Same (n=64)	296	568	347	316	356	296	468	211	246	246
Differ (initial) (n=32)	214	529	200	235	331	124	258	125	152	191
Differ (final) (n=32)	456	676	411	462	453	330	492	302	379	330

Table 22. Controls' mean reaction times (ms) to same pairs and to pairs with syllable-initial and syllable-final contrasts in nonword discrimination

As expected, responses were faster to pairs that differed on the initial segment (mean 236 milliseconds) than to the same pairs (mean 335 milliseconds). This difference was highly significant (ANOVA p = .001**). There was also a highly significant effect of participant (ANOVA p <.001**) and a significant interaction between match and participant (ANOVA p = .009*). The interaction arose from the degree to which different responses were faster than same responses for individual participants, since all controls showed the same direction of effect. In contrast, responses were faster to the same pairs than to pairs that differed on the final segment (mean 431 msecs) for all control participants. This difference was highly significant (ANOVA p <.001**). There was a highly significant effect of participant, but no interaction between match and participant (ANOVA p = .175).

Thus, when the confounding influence of the position of contrasts was taken into account, controls showed a clear and consistent effect of match on their responses to nonword pairs. It is interesting that responses were slower to syllable-final contrasts than to same pairs, since both decisions could be made at the offset of the second syllable. It may be that this pattern reveals a strategic effect or response bias, in that participants listen for similarity rather than difference between the syllables, although the data cannot confirm this. Subsequent analyses of the effect of match on reaction times were carried out separately for pairs that differed in their initial and final segments.

All the aphasic participants showed strong effects of *match* when both accuracy and reaction times were considered. AL, JW, JWh and TVR all showed a significant or highly significant overall effect of *match* on accuracy, with more errors on the different pairs (see Table 23). TDS however showed no difference in accuracy between the same and different pairs.

Match	AL	JW	JWh	TDS	TVR
Same (n=64)	97% (n=63)	97%	97%	86%	92%
Different (n=64)	68% (n=63)	60% (n=63)	86% (n=63)	84% (n=63)	80%
Chi Square Sig.	** <.001	** <.001	* .025	.433	* .042

Table 23. Effect of match on accuracy in nonword discrimination by aphasic participants

One explanation for the aphasic participants (excluding TDS) making more errors on the different pairs than the same pairs is that this resulted from impairment in the perception of phonetic contrasts. Where the participants could not discriminate the contrast between two different tokens, a false 'same' response would have been given. Alternatively, the higher number of false 'same' responses may have reflected a strategic effect or bias to respond 'same' when required to make a same-different judgement. These two possibilities are discussed below in relation to the effect of contrast type. It is interesting that TDS differed from the other aphasic participants in showing no advantage for the same pairs in his accuracy. Tyler (1992b p.71) describes the false 'different' response rate as an indicator of guessing (since discrimination difficulties should not increase error rates to the matching pairs), suggesting that many of TDS's responses were guesses. This might have occurred had he misunderstood the task, but this seems unlikely given that his performance was well above chance. A high rate of errors on the same pairs might also have arisen from a severe encoding difficulty, in that phonological encoding is so unreliable that each item in a same pair is encoded differently. However, TDS's overall level of accuracy makes this explanation seem unlikely. Alternatively, it is possible that errors on the same pairs would occur if the phonological representation of the first item in the pair decayed before the second had been processed, meaning that the same-different judgement could not be made reliably. The argument that some aphasic processing disturbances including phoneme discrimination deficits may arise from overly rapid decay of representations has been put forward by a number of authors (see chapter one). TDS's frequent need for repetition in the profiling tasks involving spoken input is consistent with his having difficulty maintaining phonological representations (see chapter three). It might be possible to determine whether rapid decay of representations were the source of some of his errors by varying the inter-stimulus interval (ISI). If representations do decay rapidly, then it would be predicted that TDS's accuracy should be inversely correlated with inter-stimulus interval. If, on the other hand, his accuracy actually improved with longer ISIs, then this might suggest that the problem was primarily one of encoding since more time could result in more accurate processing.

Four of the aphasic participants showed no main effect of position on response accuracy (see Table 24). Only JWh made more errors on initial than final contrasts, with this difference approaching significance.

Position	AL	JW	JWh	TDS	TVR
initial (n=32)	71% (n=31)	61% (n=31)	77% (n=31)	84% (n=31)	78%
final (n=32)	66%	63%	94%	81%	81%
Chi Square Sig.	.649	.921	.064	.784	.756

Table 24. Effect of contrast position on accuracy in nonword discrimination by aphasic participants

Match	AL	JW	JWh	TDS	TVR
Same (n=64)	951	458	384	1644	895
Different **(initial)** (n=32)	987	788	296	1041	887
Different **(final)** (n=32)	1472	840	507	1439	990

Table 25. Mean reaction times (ms) to same pairs and to different pairs with syllable-initial and syllable-final contrasts in nonword discrimination for aphasic participants

All of the aphasic participants had faster mean reactions to initial than final contrasts (see Table 25). This difference was highly significant for JWh (p =.002**) and TDS (p =.005**), and significant for AL (p = .011*), but was not significant for either JW or TVR (p >.100). JW, JWh and TDS all responded faster to pairs that differ on the initial segment than to same pairs. This difference was highly significant for JW (p = .004**) and TDS (p <.001**), and just short of significance for JWh (p = .066). AL and TVR showed no difference between reaction times to same pairs and to pairs that differ on the initial segment (p > .8). AL, JW and JWh all responded slower to pairs that differ on the final segment than to same pairs. This difference was significant for JWh (p =.006*) and highly significant for AL (p =.001**) and JW (p <.001**). TDS and TVR also showed slightly slower mean reaction times to pairs that differ on the final segment than to same pairs, but this difference was not significant (p > .100).

Thus the aphasic participants overall showed a similar pattern to the control group of the effects of match and position on reaction times. They tended to respond faster to initial contrasts, and slower to final contrasts, than to same pairs of nonwords. This suggests that they too make the same-different judgement for nonwords on the basis of representations that maintain temporal aspects of the acoustic signal.

Effects of phonetic contrast type

The different pairs of nonwords consisted of equal numbers of four types of phonetic contrast: voice, place, manner, and two-feature combinations. It has previously been demonstrated that controls (including groups of younger adults, older adults with normal hearing, and older adults with mild-moderate hearing loss) make more errors discriminating place contrasts than voice contrasts (in a study of word discrimination by Tyler 1992b p.70). Analysis of the effect of contrast type on reaction times in the current experiment was carried out separately for syllable-initial and syllable-final contrasts, to avoid confounding the results with effects of syllable-position. For contrasts that occur in syllable initial position, controls showed a highly significant effect of contrast type (ANOVA $p < .001^{**}$) (see Table 26). There was also a highly significant effect of participant ($p < .001^{**}$), but no interaction between participant and contrast ($p = .593$).

Contrast	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
2f (n=8)	122	432	136	82	261	46	154	83	66	146
M (n=12)	141	474	209	169	263	134	219	135	164	202
P (n=4)	286	620	201	231	345	110	263	82	167	164
V (n=8)	375	665	256	525	519	193	420	179	216	238

Table 26. Nonword discrimination: controls' mean reaction times (ms) for contrast types in syllable-initial position

Post hoc Tukey's Honestly Significant Difference (HSD) tests revealed consistent and significant patterns (see Table 27). There were three partially overlapping subsets of contrast type in initial position according to controls' speed of response. The fastest response subset included two feature and manner contrasts, with a medium response speed subset including manner and place contrasts. Responses to voice contrasts were significantly slower than responses to any other contrast type, suggesting that in syllable-initial position they are more difficult to discriminate.

Contrast	N	Subset		
		1	2	3
2 feature	78	154		
manner	119	212	212	
place	39		249	
voice	74			359
Sig.		.350	.715	1.000

Table 27. Homogeneous subsets of initial contrast types according to controls' reaction times (ms) in nonword phoneme discrimination.

The effect of contrast type on controls' reaction times was also highly significant for contrasts in syllable-final position (ANOVA p <.001**) (see Table 28). The effect of participant was highly significant (ANOVA p <.001**), and there was no interaction between contrast and participant (ANOVA p = .497).

cont	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
2f (n=8)	522	576	349	433	413	249	408	302	316	302
M (n=4)	293	543	303	342	400	239	438	200	353	299
P (n=12)	489	685	484	519	495	358	563	310	446	377
V (n=8)	420	852	428	471	462	413	507	341	350	311

Table 28. Nonword discrimination: controls' mean reaction times (ms) for contrast types in syllable-final position

Two distinct subsets of syllable-final contrast types according to control reaction times were revealed by Post hoc Tukey HSD tests. Responses were fastest for manner and 2-feature contrasts, and slowest for voice and place contrasts. These results are shown in Table 29 and suggest that in syllable-final position both voice and place contrasts are more difficult to discriminate than manner or two-feature contrasts. Differences in the acoustic cues to voicing and place of articulation were discussed in chapter one, in that voicing contrasts are more heavily dependant on temporal cues, while place contrasts are more heavily dependant on spectral cues. The reason why both of these types of contrast are more difficult to discriminate than either manner or two-feature contrasts, is that these latter are clearly signalled by both temporal and spectral cues. Such differences in inherent discriminability of the different types of contrast, and the acoustic cues that underlie them, will prove important in evaluation of two connectionist models of speech perception discussed in chapter seven.

Contrast	N	Subset	
		1	2
manner	40	341	
2 feature	80	387	
voice	76		459
place	113		475
Tukey HSD Sig.		.257	.928

Table 29. Homogeneous subsets of final contrasts for controls' reaction times (ms) in nonword discrimination

It has been reported in the literature that some aphasic listeners are differentially impaired in the encoding of specific types of phonetic feature (see chapter one). For instance, Basso, Casati & Vignolo (1977), Saffran, Marin & Yeni-Komshian (1976) and Miceli, Caltagirone, Gainotti & Payer-Rigo (1978) have described aphasic listeners who were unable to reliably process voicing contrasts, while Caplan & Aydelott-Utman (1994) and Tyler (1992b) have described individuals who had difficulty in discriminating place contrasts. Such findings are consistent with the performance of the aphasic participants in this study. The effect of contrast type on response accuracy was significant for all of the aphasic participants except for TVR (see Table 30).

Nonword Discrim	AL	JW	JWh	TDS	TVR
Voice (n=16)	60% (n=15)	31%	63%	63%	69%
Place (n=16)	19%	33% (n=15)	81%	67% (n=15)	75%
Manner (n=16)	100%	81%	100% (n=15)	100%	81%
2 Features (n=16)	94%	100%	100%	100%	94%
Chi Square Sig.	<.001**	<.001**	.006*	.003**	.337

Table 30. Effects of contrast type on aphasic participants' accuracy in nonword discrimination

Overall, the aphasic participants made more errors on voice and place contrasts, although individual differences were found. JWh and TDS both made errors only on voice and place contrasts, while AL and JW also made errors on either manner or two feature contrasts. Scores were strikingly low on place contrasts for AL and on both place and voice contrasts for JW. TVR made errors on all contrast types and showed no significant effect of contrast. However, his pattern was not entirely dissimilar to the other aphasic participants, since he also made more errors on voice and place contrasts than on manner or two-feature contrasts. It is interesting to note that the same contrasts that produced higher error rates for the aphasic group also produced slower responses for the control group, suggesting that voice and place contrasts are inherently more difficult to process than manner contrasts (see below for discussion).

Response accuracy to the four contrast types was then analysed separately for syllable-initial and syllable-final contrasts, because the acoustic cues to contrasts (particularly for voicing) differ according to whether the contrasts occur before or after a vowel. If participants had difficulty in processing specific acoustic cues, this might produce different patterns in the effect of contrast type for syllable-initial and syllable-final contrasts.

Nonword Discrim	AL		JW		JWh		TDS		TVR	
	I	F	I	F	I	F	I	F	I	F
Voice I (n=8) F(n=8)	14% (n=7)	100%	0%	63%	25%	100%	38%	88%	63%	75%
Place I (n=4) F (n=12)	25%	18%	25%	25%	75%	83%	100% (n=3)	58%	100%	67%
Manner I (n=12) F (n=4)	100%	100%	75%	100%	100% (n=11)	100%	100%	100%	75%	100%
2 Features I (n=8) F(n=8)	100%	88%	100%	100%	100%	100%	100%	100%	88%	100%
Chi Square Sig.	** .000	** .000	** .000	** .002	** .000	.314	** .001	.068	.433	.199

Table 31. Effects of contrast type on aphasic participants' accuracy for syllable-initial and syllable-final contrasts in nonword discrimination.

AL, JW, JWh and TDS all showed highly significant effects of the type of phonetic contrast on their accuracy of response to contrasts in syllable-initial position, with almost all of their errors involving either voice or place contrasts (see Table 31). The effect of contrast type for syllable-final contrasts was also highly significant for AL, JW and TDS. Each of them showed strikingly low accuracy for final place contrasts, with JW and TDS also making some errors on voice contrasts. JWh followed a similar pattern with her only syllable final errors involving place contrasts, but for her the difference was not significant since she performed almost at ceiling. Group analysis of aphasic data was carried out to see whether these patterns were significant across the group. In initial position, the mean accuracy for the group on voice contrasts was 28%, and on place contrasts 65%, whereas in final position mean accuracy for voice was 85% and for place 50%. There were highly significant effects of contrast type on accuracy both in syllable-initial position (chi square p = <.001**) and syllable-final position (chi square p <.001**).

These results suggest that four of the aphasic participants have specific impairments in the encoding of voice and place contrasts. It is interesting to note that AL, JW, JWh and TDS were all able to discriminate voicing contrasts more accurately when they occurred in syllable-final position. This was particularly striking for AL and JWh, both of whom scored 25% on initial voice contrasts and 100% on final voice contrasts, and also JW whose performance differed from 0% to 63%. Such strong advantages for final voicing contrasts suggests that these participants have difficulty in encoding the temporal cue of voice onset time, but may be better able to perceive the more salient differences in vowel length associated with syllable-final voicing contrasts in English. This is in keeping with the findings of Tyler (1992b p.72) who showed that hearing impaired controls made more errors in discriminating voicing contrasts in initial than final position. The finding also relates to the control group pattern, in which responses to voicing contrasts in initial position were significantly slower than to any other contrast type, while in final position responses to voicing contrasts were similar to responses to place contrasts. It is likely that JW's errors are due in part to his high frequency hearing loss, although the number and distribution of errors is much greater than would be predicted on the basis of his hearing levels alone. It is also possible that a difficulty in holding and comparing two representations may have contributed to some of JW's errors, as discussed in relation to his performance on auditory synonym judgement (see chapter 3). With regard to discrimination of place contrasts, only TDS and TVR showed a difference in accuracy according to the syllable position of the contrast, and these differences were less extreme than those demonstrated for voicing contrasts. This is presumably because the acoustic cues to place of articulation vary less according to syllable-position than do the acoustic cues to voicing.

Although TVR's accuracy on this task was well below the range of the control group, he did not show any statistically significant effect of contrast type in either syllable-initial or syllable-final position. Like the other aphasic participants, most of his errors in initial position involved voice contrasts, but unlike them he also made errors on both manner and two-feature contrasts. His pattern of accuracy for syllable-final contrasts was similar to the other aphasic participants in that he made errors only on place and voice contrasts. It is therefore possible that TVR also exhibits an impairment in the encoding of voice and place contrasts, but the evidence is inconclusive. It is also possible that some of his errors may have been due to difficulties in encoding vowels rather than consonants, as suggested for his performance on auditory rhyme judgement (see chapter three). The fact that his errors, at least for syllable-initial contrasts, were dispersed across all four contrast types may however suggest that TVR's difficulties with this task stemmed not from a specific impairment in phonological encoding, but from a more generalised auditory processing impairment. This might involve, for instance, difficulty attending to rapid auditory stimuli such as claimed by Tallal & Newcombe (1978) to account for auditory processing difficulties in aphasic listeners. There were certainly some suggestions that TVR may have slight attentional difficulties based on his performance on the BORB object decision test, and on the Role Video test (see chapter three), although the nature of attentional processes in these tasks and in phoneme discrimination are clearly different. Alternatively, a general auditory processing difficulty might arise from deficits in holding phonological representations. This might prevent accurate comparison between two nonwords, since the representation of the first would rapidly decay whilst the second was processed (as claimed by Martin, Breedin & Damian (1999), and by Nakakoshi et al (2001) - see chapter one). If place and voice contrasts are, as claimed, inherently more difficult to process than manner and two-feature contrasts, then either of these generalised auditory processing impairments might be predicted to disproportionately affect processing of place and voicing. This would result in widespread errors with higher error rates on these contrasts, as shown by TVR.

The patterns of aphasic participants' reaction times according to contrast type were less clear than the patterns of accuracy (see Table 32) For contrasts in syllable-initial position, only JW and JWh showed significant effects of the type of contrast. Post Hoc Tukey HSD tests revealed that JW's responses to syllable-initial two-feature contrasts were faster than his responses to manner contrasts. JWh's pattern was more similar to that shown by the controls, with faster responses to two feature and manner contrasts and slower responses to place and voice contrasts. In final position only AL showed a significant effect of contrast type, but post hoc Tukey HSD tests revealed neither any significant differences between reaction times to any two contrast types, nor any subsets of contrast types.

Nonword Discrim	AL		JW		JWh		TDS		TVR	
	I	F	I	F	I	F	I	F	I	F
Voice I (n=8) F(n=8)	1581	1916	639	1085	568	534	1143	1433	1115	954
Place I (n=4) F (n=12)	897	1133	537	724	432	528	1022	1691	854	1033
Manner I (n=12) F (n=4)	845	2040	1344	786	191	385	899	1322	811	1054
2 Features I (n=8) F(n=8)	723	1213	268	889	86	512	1174	1123	818	927
ANOVA Sig.	.101	* .021	* .022	.585	** <.001	.747	.607	.177	.276	.755

Table 32. Effects of contrast type on aphasic participants' reaction times (ms) for syllable-initial and syllable-final contrasts in nonword discrimination.

The results of the nonword discrimination task can be summarised as follows. Controls responded faster to initial contrasts than to same pairs, and faster to same pairs than to final contrasts. They also responded faster to two-feature and manner contrasts than to voice and place contrasts in both initial and final positions. All of the aphasic participants except TDS made more errors on different than same pairs, and they mainly showed a similar pattern to the controls in their reaction times for the factors of match and position. Aphasic participants tended to make more errors on place and voice contrasts, but their patterns of reaction time data were less clear. It is unsurprising that reaction time data are less revealing for the aphasic participants than for the control group. As discussed by Tyler (1992b p.278-9), aphasic participants tend not only to respond more slowly than controls across a wide range of tasks, but also to be more variable in their response speed. Comparison of the distributions of reaction times for control and aphasic groups confirmed this to be the case here. While the range of reaction times for the controls in nonword discrimination was 4256 milliseconds (S.D. = 293, Variance = 85,915), the range for the aphasic group was 8813 milliseconds (S.D. = 964, Variance = 929,697). Thus there was far greater variability in the aphasic data. This, coupled with the facts that the individual analyses of aphasic reaction times are based on only one tenth the number of cases included in control group analyses, and that there are relatively few examples of each contrast type in each syllable-position, makes it extremely difficult to show effects of contrast type on speed of processing.

Phoneme Discrimination in Words Results

On the word discrimination task the control group's mean score was 98% (range = 97-99% raw score range = 124/128-127/128 SD = .141). Accuracy levels on word discrimination were below the control group's range for four of the aphasic participants, and the mean score for the aphasic group was 88% (aphasic range = 80-98 % raw score range = 103/128-122/125 SD = .321). The difference in accuracy between control and aphasic groups was significant (chi square $p < .001^{**}$).

Effects of match and position

As in the nonword discrimination task, the word discrimination stimuli consisted of equal numbers of same and different pairs, with the set of different pairs being balanced for contrasts in syllable-initial and syllable-final positions.The controls responded faster to pairs that differed in the initial segment (mean 262 milliseconds) than to pairs that differed in the final segment (mean 447 milliseconds) (ANOVA $p < .001^{**}$) (see Table 33). There was also a highly significant effect of participant (ANOVA $p = .003^{**}$) and a highly significant interaction between participant and position (ANOVA $p = .001^{**}$). The source of this interaction was explored. It was observed that every control except WB clearly responded faster to initial than final contrasts. When ANOVA was carried out separately for each control, all participants except WB showed a highly significant effect of position while WB showed no effect. To determine whether the interaction between participant and position had arisen from this difference between WB and the other controls, the analysis was repeated on the group data excluding WB's responses. Although this reduced the significance of the interaction, even without WB there was a highly significant effect of participant (ANOVA $p = .002^{**}$) and a highly significant interaction between participant and position (ANOVA $p = .005^{**}$). It was concluded that the interaction arose from differences between participants in the degree to which their responses were faster to initial contrasts, and that the normal pattern is to respond faster to initial than final contrasts in word pairs.

Reaction times to syllable-initial and syllable-final contrasts were then compared to reaction times for the same pairs. Controls responded faster to word pairs that differed on the initial segment than to the same pairs (mean 327 milliseconds) (ANOVA $p = .001^{**}$). There was a highly significant effect of participant (ANOVA $p <.001^{**}$), and no interaction between participant and match (ANOVA $p = .342$). They responded faster to the same pairs than to pairs that differed in the final segment (ANOVA $p <.001^{**}$). Again there was a highly significant effect of participant (ANOVA $p <.001^{**}$), and this time there was a significant interaction between match and participant (ANOVA $p = .009^{*}$). This interaction arose from the degree to which responses to the same pairs were faster, since all controls showed the same direction of effect.

Match	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
Same (n=64)	304	445	356	296	385	185	415	165	234	490
Initial contrast (n=32)	220	353	320	293	304	64	308	144	136	482
Final contrast (n=32)	511	653	429	479	434	300	537	277	328	522

Table 33. Controls' mean reaction times (ms) to same and different pairs in word phoneme discrimination

Thus the pattern of control reaction times for same and different pairs of words was very similar in both word and nonword discrimination. Responses were fastest to initially contrasting pairs, followed by same pairs, and slowest to finally contrasting pairs. Repeated measures tests were carried out to compare the effect of match between nonword and word discrimination tasks. These revealed no interaction between lexicality, match and participant for contrasts in initial position (repeated measures $p = .187$) nor in final position (repeated measures $p = .348$). This confirmed that the effect of match was the same in both nonword and word pairs for the controls.

This finding is of interest because it provides an insight into levels of processing in this task. When participants hear words, it is assumed that representations are automatically activated at phonetic, phonological, lexical and semantic levels. The same-different judgement could potentially be made at any of these levels. The fact that responses were faster to initial than final contrasts, and patterned very similarly to nonword responses, implies that the judgement was being made at phonetic or phonological levels (both of which are temporally encoded). This lends support to claims by some authors (e.g. Connine & Clifton 1987; Miller 2001) that auditory speech perception is driven primarily from the bottom-up by acoustic features, with at most limited effects of higher level representations.

Accuracy levels on word discrimination were below the control group's range for four of the aphasic participants (see Table 34). The exception was JWh, who like the controls performed almost at ceiling on this task. Binary logistic regression analyses were carried out (using the forward likelihood ratio method) to determine whether overall accuracy levels were different for the nonword and word discrimination tasks. These revealed that, where there was a difference in accuracy, the advantage was for word discrimination. AL showed a trend towards an effect of lexicality (logistic regression $p = .065$), while for JWh this was significant (logistic regression $p =.025$*). Analysis of the whole group's data revealed a trend towards fewer errors on words than nonwords when all items were included (binary logistic regression $p= .070$). Since most errors on both of these tasks involved the different pairs, the group analysis was repeated excluding the same pairs, and demonstrated that accuracy was significantly higher overall on words than on nonwords (binary logistic regression $p =.017$*). This mirrors the finding reported in chapter four that the aphasic group showed a highly significant effect of lexicality on lexical decision, with more errors on nonwords than on words.

Of the four aphasic participants who made a substantial number of errors in word discrimination, JW and TDS both made more errors on the different pairs with this effect being highly significant. AL and TVR showed no significant difference in accuracy to same and different pairs.

Match	AL	JW	JWh	TDS	TVR
same (n=64)	94% (n=63)	98%	98% (n=63)	92%	84%
different (n=64)	87% (n=63)	72%	97% (n=63)	69%	92%
Chi Square Sig.	.225	** <.001	.559	** .001	.169

Table 34. Effect of match on accuracy in word phoneme discrimination by aphasic participants

Logistic regression analyses were carried out to determine whether the effect of match on accuracy differed between the nonword and word discrimination tasks. The results revealed different patterns for the individual participants. JW showed a main effect of match (p <.001**), but no interaction between match and lexicality. TDS also showed a main effect of match (p =.002**), and interestingly showed an advantage for the same pairs only in the word discrimination task. This interaction between match and lexicality approached significance (p =.07), but was not included in the model which employed a cut-off point of p <.05. AL showed a main effect of match across the two tasks that was just short of significance (p =.057), as well as an interaction between match and lexicality (p =.009*). This interaction arose from his significant advantage for the same pairs in nonword discrimination, but not in word discrimination. JWh and TVR also showed highly significant interactions between match and lexicality arising from an advantage for the same pairs in nonword discrimination, but not in word discrimination (logistic regression for JWh p =.001**; for TVR p =.05*). Thus three of the aphasic participants made significantly more errors on the different pairs, suggesting difficulty in discriminating phonetic contrasts, only when the stimuli were nonwords. This is discussed further below in relation to the effect of contrast type.

Aphasic participants' performance on the different word pairs was further analysed to determine whether there was any effect of the position of contrasts on accuracy of response. Four of the aphasic participants showed no effect of contrast position on accuracy in word discrimination, and JW showed a non-significant trend (see Table 35). When data were analysed for the group this also revealed no effect of syllable-position on accuracy (chi square p =.437). This finding is in keeping with Tyler's (1992b) finding that contrast position did not affect accuracy in aphasic word discrimination. However, it is different to that reported by Gardner, Albert & Weintraub (1975) (as discussed in chapter one), who showed that aphasic listeners tended to confuse words that shared the same onset rather than words that had different onsets but shared the same ending. This difference in results can be accounted for by the fact that Gardner et al used a comprehension rather than a pure discrimination task. Similar patterns to those reported by Gardner will be shown in an experiment that involves both discrimination and comprehension (see chapter six). The effect of the position of contrasts on response accuracy was compared between nonword and word discrimination tasks. None of the aphasic participants showed a significant difference in effect between the two tasks, although JWh did show a trend towards an interaction between position and lexicality (logistic regression p =.064), reflecting the fact that almost all her errors on nonwords involved initial contrasts while she made very few errors at all in word discrimination.

Position of contrast	AL	JW	JWh	TDS	TVR
initial (n=32)	88%	63%	97% (n=30)	75%	88%
final (n=32)	87% (n=31)	81%	97%	63%	97%
Chi Square Sig.	.962	.095	1	.281	.756

Table 35. Effect of contrast position on accuracy in word discrimination by aphasic participants

The position of contrasts in the word pairs had surprisingly little effect on the reaction times of the aphasic participants (see Table 36). Only JWh responded significantly faster to initial than final contrasts (ANOVA p =.01*), which was a much weaker effect than she had shown in nonwords. JW also showed a trend towards an effect (ANOVA p =.063), while the other three participants showed no difference in reaction times (ANOVA p >.15). There was no effect of position on reaction times for the group (ANOVA p =.137), nor was there an interaction between position and participant (ANOVA p =.286). This compares with the fact that all the aphasic participants had faster mean reactions to initial contrasts in nonword discrimination (with three individuals having shown significant effects), which was interpreted as evidence that they were making the nonword same-different judgement on the basis of temporally encoded representations.

Match	AL	JW	JWh	TDS	TVR
Same (n=64)	1321	518	338	1413	977
Different (initial) (n=32)	1497	578	349	1841	895
Different (final) (n=32)	1412	731	660	2302	900

Table 36. Mean reaction times (ms) to same and different pairs in word discrimination by aphasic participants.

This pattern is different from the control group, who responded faster to initial than final contrasts in both nonword and word discrimination. It may suggest that the aphasic listeners relied more heavily than the controls on a level of representation that does not carry temporal information (such as the semantic level) to make the same-different judgement for the word pairs. However, comparison of reaction time distributions for the group across nonword and word tasks revealed that responses to words were slower and more variable than responses to nonwords (words mean 1006 milliseconds S.D. 881; nonwords mean 897 milliseconds S.D. 644). While this difference was not significant overall (ANOVA p =.201), there was an interaction between lexicality and participant that showed reaction times to words were slower and more variable for some individuals (ANOVA p =.003). Thus it may be that the lack of an effect of position on aphasic reaction times in this task may be due at least in part to response variability, although some significant reaction time patterns were detected when position and match were analysed together (see below). Even if it is the case that aphasic listeners rely more heavily than controls on lexical-semantic levels of representation, this does not suggest that phonological representations are redundant in the decision making process. It suggests only that semantic representations may be of greater importance for the aphasic participants than the controls.

Indeed, JWh did show a significant effect of position on her reaction times, but it is worth remembering here that JWh's accuracy on this task was at ceiling and within the range of the controls. This suggests that she was able to encode the phonetic features in words accurately, and may not therefore have needed to rely on semantic representations to assist her judgements. Like the controls, perhaps JWh could reliably compare phonological representations, although the relative weakness of the effect in word discrimination (compared to nonwords) may still indicate some reliance on semantic representations. JW also showed an influence of position on his reaction times in words, but was unlike JWh in that his accuracy was below the control range. JW may have been unable to rely on access to semantics to the same degree as AL, TDS and TVR, since he clearly showed difficulty in accessing semantic representations from spoken words on Spoken Word to Picture Matching and on Auditory Synonym Judgement (see chapter three). He was also the only of the aphasic participants to show no effect of imageability on auditory lexical decision, visual lexical decision, or auditory synonym judgement, suggesting that his difficulties affected pre-semantic processing. It was suggested in chapter four that, without a picture or other context to support his semantic access, JW may be unable to generate sufficient semantic activation from spoken words for imageability to have any effect on his lexical processing. This would be consistent with his being unable to rely on access to semantic representations to assist discrimination of spoken word pairs.

Thus there appear to be individual differences in the relative weightings of levels of representation that are most salient in word discrimination. The levels that are most heavily weighted may be dependant on each participant's ability to access either phonological or semantic representations of words. Where phonological representations can be activated reliably, such as for the controls and JWh, the judgement may be made primarily at the phonological level so producing an effect of syllable-position on speed of processing. However, those listeners who have unreliable phonological encoding may rely more heavily on their relatively stable lexical or semantic representations to inform their decisions. Although some models of speech perception (such as Ellis & Young 1988) do not support the suggestion that lexical and semantic representations may be accessed reliably despite poor phoneme discrimination, evidence of such a dissociation in some aphasic participants has been reported (e.g. Caplan & Utman 1994). The use of semantic representations to assist discrimination could of course only be effective where access to semantic representations from auditory input was reasonably robust. However, it has been shown that JW is not reliably able to access semantic representations of spoken words. He may still therefore make discrimination judgements primarily at the phonological level, even though these judgements are unreliable.

The aphasic groups' reaction times to the same and different word-pairs were then compared (see Table 36). Four of the aphasic participants showed no difference in speed of response to pairs that differed in their initial syllable than to same word-pairs (ANOVA $p > .2$). TDS was the only aphasic participant to show a trend towards an effect of match, but with faster responses to same pairs than to initially contrasting pairs (ANOVA $p = .064$). Thus TDS showed an advantage in both his accuracy and his reaction times for processing the same pairs in word discrimination. The aphasic participants' patterns were once again different to the control group, who had shown faster responses to the initially-contrasting pairs in both nonword and word discrimination tasks. The effect of match on aphasic reaction times for same pairs and pairs that contrasted in the initial segment was compared between the nonword and word tasks. This revealed a difference in the effect for three of the participants, all of whom had responded faster to the different pairs in the nonword condition but not the word condition (repeated measures for JW $p = .003$**; JWh $p = .075$; TDS $p = .001$**). This lack of an advantage for processing syllable-initial contrasts over same pairs in word discrimination may support the notion that the aphasic participants' decisions were weighted more heavily by non-temporal semantic representations.

JW, JWh and TDS were also alike in having faster responses to the same word-pairs than to pairs that differed in the final segment (ANOVA for JW $p = .009$*; for both JWh and TDS $p < .001$**). These three participants showed significant differences in the effect of match between the word and nonword discrimination tasks (repeated measures for JW p = .043*; JWh p = .020*; TDS p <.001**). Both JW and JWh differed only in the degree to which their responses were faster to the same pairs in each task; for JWh the mean advantage for the nonword same-pairs was 136 milliseconds, while in words it was 303 milliseconds, whereas JW showed a mean advantage of 384 milliseconds for the nonword same-pairs, and of 188 milliseconds for the word same pairs. TDS, showed a different direction of effect across the two tasks, since in nonword discrimination he responded faster to the finally contrasting pairs, but in word discrimination he responded faster to the same pairs. These effects were not significant for TDS in either task and may reflect normal variability, since the controls also varied in the strength of effect of match for final contrasts in word pairs (as shown by the interaction between match and participant). Neither AL nor TVR showed any difference in reaction times to finally-contrasting and same pairs in word discrimination (ANOVA p >.3). Both of them showed a trend towards a difference in the effect of match between the nonword and word tasks, since they had responded faster to the same pairs of nonwords (repeated measures for AL p = .077; TVR p = .091).

Effects of phonetic contrast type

The control group showed no effect of the type of phonetic contrast on their speed of response for word pairs that differed in the initial segment (ANOVA p = .270) (see Table 37). The effect of participant was highly significant (ANOVA p <.001**), and there was no interaction between participant and contrast (ANOVA p = .309).

Initial contr.	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
2f (n=8)	240	247	273	245	285	58	224	103	175	442
M (n=12)	258	328	329	216	340	80	329	125	146	506
P (n=4)	271	675	501	325	267	66	331	156	164	374
V (n=8)	87	333	265	440	280	44	348	210	78	541

Table 37. Controls' mean reaction times (ms) for syllable-initial contrast types in word discrimination

This pattern was therefore quite different to that found in nonword discrimination, where controls had shown a highly significant effect of contrast type on reaction times to syllable-initial contrasts. Comparison of reaction times in nonword and word discrimination revealed a highly significant difference between the effects of contrast in the two tasks (repeated measures $p < .001$**). There was no interaction between this effect and the effect of participant (repeated measures $p = .946$).

One possible explanation for this difference in processing of nonwords and words relates to the mechanisms for the activation of lexical candidates (see chapter one). Studies that have looked at the priming effects of word fragments (e.g. Marslen-Wilson 1987; Marslen-Wilson & Zwitserlood 1989) have demonstrated that lexical activation is triggered almost immediately by word onsets, and adjusted in accordance with subsequent acoustic-phonetic information. Thus we might assume that any effect of contrast type on responses to word onsets demonstrates the effect of phonetic factors on phonological and/or lexical activation. Conversely, a lack of effect of contrast type may indicate that non-phonetic factors are exerting a stronger influence on activation. In word discrimination, it is likely that the participant's representations (phonological, lexical and/or semantic) of the first word in the pair will still be highly active at the onset of the second word. This lingering activation of the first word's representations at the onset of the second word may have a sufficiently strong effect to mask the influence of phonetic features on reaction times.

This account is conjecture and does not specify the levels of representation that might exert or be influenced by this 'lingering activation', since the raised activation levels could involve the acoustic-phonetic, lexical or semantic levels. However, the difference between the effect of contrast type in initial position on word and nonword processing may indicate that the effect is not occurring at the acoustic-phonetic level. If it were a prelexical representation (or acoustic trace) of the first syllable that was still active at onset of the second syllable, then a similar pattern of lingering activation would be predicted for both nonword and word pairs. Since the patterns found on words and nonwords were different, this suggests that any lingering activation must be at lexical and/or semantic levels of representation. Indeed, it has been demonstrated that the priming effects of semantic representations on word retrieval remain active much longer than those of phonetic representations (Howard et al. 1985).

However, for contrasts in syllable-final position the control group did show a highly significant effect of the type of contrast on their reaction times (ANOVA $p < .001^{**}$) (see Table 38). There was a highly significant effect of participant (ANOVA $p < .001^{**}$), and no interaction between these two factors ($p = .999$).

Final feat.	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
2f (n=8)	457	551	354	396	420	242	466	222	258	522
M (n=4)	550	684	419	477	413	287	589	281	328	472
P (n=12)	538	673	477	566	481	378	594	345	414	533
V (n=8)	510	721	438	439	380	246	496	230	263	532

Table 38. Controls' mean reaction times (ms) to syllable-final contrast types in word discrimination

Under the 'lingering activation' account, lexical activation at the time of onset of the second word may have been influenced by factors other than the bottom-up processing of the acoustic signal. If this account were valid, it could be argued that there would similarly be no effect of contrast type on the speed of processing final contrasts in words. However, the offset of each monosyllabic word used in this experiment coincides with that word's uniqueness point. As discussed in chapter one, it is at the uniqueness point that a word diverges from its neighbourhood cohort, enabling the target lexical representation to be selected. Thus, for these words it can be assumed that the effects of contrast type in syllable-final position reflect the influence of phonetic factors on lexical selection more than on activation. The fact that controls show a very strong effect of contrast type at the ends of words is consistent with their lexical selection being more strongly reliant on phonetic cues than top-down feedback.

Post hoc Tukey HSD tests were carried out to explore the word-final contrast effect (see Table 39). These revealed two overlapping subsets of phonetic contrast type according to reaction times. Responses were fastest to two feature contrasts, followed by voice and manner contrasts, and slowest to place contrasts.

Contrast	N	Subset	
		1	2
2 feature	80	389	
voice	74	428	428
manner	40	450	450
place	116		500
Tukey HSD Sig.		.168	.074

Table 39 Homogeneous subsets of syllable-final contrast types in word discrimination revealed by post hoc tests of controls' reaction times (ms).

This differs from controls' responses to syllable-final contrasts in nonword discrimination, where the slowest responses were to voice contrasts. These patterns were compared statistically across the two tasks. A significant difference was found between the effect of contrast type on controls' reaction times across the two tasks (repeated measures $p = .012$*). There was no interaction between this effect and the effect of participant (repeated measures $p = .983$). Thus, while there were highly significant effects of contrast type in both nonword and word discrimination tasks, there was some variation in the rank speed of contrast types between these two tasks. This was surprising, since differences in latencies for different contrast types are assumed to reflect the processing of acoustic cues at prelexical levels of representation. It might be that uncontrolled factors related to the word items (such as neighbourhood size, familiarity, or number of related senses of individual words) may have influenced speed of processing. It is also possible that nonwords may have been subject to neighbourhood density effects (as described by Luce & Large 2001) that were not controlled here. These possibilities would merit further investigation.

An important point is that the finding that controls process word-final contrasts on the basis of the acoustic signal more strongly than they do word-initial contrasts appears to conflict with Samuel's (1990) study of phoneme restoration (see chapter one). He found that listeners were more likely to restore missing phonemes when the altered word was cued by an unaltered token of the same word, and that this effect increased for later occurring phonemes. He accounted for this finding by suggesting that listeners' perceptions of the word-endings were less reliant on the acoustic signal, and more reliant on lexical activation, than their perceptions of the word-onsets. However, this apparent difference in direction of effect between Samuel's study and that reported here is probably due to the acoustic information in his experiment being impoverished by noise, while in this study the acoustic signal is clear and unambiguous. Listeners in Samuel's study may therefore have relied more heavily on top-down information flow than listeners in this experiment, who were able to base their judgements on reliable bottom-up information. The implications of these patterns will be discussed further in chapter six, in relation to strategy use by normal and aphasic listeners.

Aphasic participants varied in the effect of contrast type on accuracy in word discrimination, with only JW and TDS showing significant effects (see Table 40). This compares to nonword discrimination, where both AL and JWh had shown significant overall effects of contrast type.

Word Discrim	AL	JW	JWh	TDS	TVR
Voice (n=16)	75%	56%	94%	69%	81%
Place (n=16)	80% (n=15)	44%	94% (n=14)	38%	94%
Manner (n=16)	94%	94%	100%	75%	94%
2 Features (n=16)	100%	94%	100%	94%	100%
Chi Square Sig.	.120	.001**	.559	.007*	.249

Table 40. Effects of contrast type on aphasic participants' accuracy in word discrimination

When the effect of contrast type on accuracy was analysed separately for syllable-initial and syllable-final contrasts, again only JW and TDS showed any significant effects (see Table 41). Although the effects for the other aphasic participants were not statistically significant, it is worth considering the patterns of raw scores here. Because the number of cases of each feature type in each position is small (with a maximum of twelve cases per contrast type) when analysed separately for each participant, the power of the statistical tests is limited. Nevertheless, the error patterns do seem to reveal clear processing patterns.

Word Discrim	AL		JW		JWh		TDS		TVR	
	I	F	I	F	I	F	I	F	I	F
Voice I(n=8) F(n=8)	63%	88% (n=7)	25%	88%	88%	100%	63%	75%	63%	100%
Place I(n=4) F(n=12)	100%	73%	0%	58%	100% (n=2)	92%	25%	42%	100%	92%
Manner I(n=12) F(n=4)	92%	100%	92%	100%	100%	100%	83%	50%	92%	100%
2 Features I(n=8) F(n=8)	100%	100%	88%	100%	100%	100%	100%	88%	100%	100%
Chi Square Sig.	.091	.284	** <.001	.068	.377	.632	* .028	.161	.091	.632

Table 41. Effects of contrast type on aphasic participants' accuracy in word discrimination, analysed separately for initial and final contrasts.

For word-pairs that differ on the initial segment, all of the aphasic participants made errors on voice contrasts, with JW having a particularly low score. JW and TDS also made many errors on place contrasts, with JW not discriminating any place contrasts correctly. All the participants except for JWh made a small number of errors on manner contrasts, with only JW making any errors on two-feature contrasts. The effect of contrast type on accuracy was significant for JW and TDS and approached significance for AL and TVR, while JWh's score was close to ceiling. For word pairs that differ on the final segment, all five participants made errors on place contrasts, with JW and TDS showing particularly high error rates. This is reminiscent of the patient JG described by Tyler (1992b p.74), who made more errors on word final contrasts, particularly those involving place of articulation. AL, JW and TDS also made a smaller number of errors on voice contrasts. Only TDS made errors on manner and two-feature contrasts. The effect of syllable-final contrast type on accuracy was not significant for any individual, although it approached significance for JW.

There were therefore strong similarities among the error patterns of the aphasic participants, with more than half the errors on initial contrasts involving voicing, and almost three-quarters of the errors on final contrasts involving place of articulation. The analyses were repeated for the aphasic participants as a group, to determine whether these apparent similarities would amount to statistically significant effects given sufficient cases for the analysis. The group analysis revealed highly significant effects of contrast type on accuracy in both syllable-initial position (chi square p <.001**) and syllable-final position (chi square p = .002**). This suggests that contrast type did have an important effect on aphasic processing accuracy for words. However, the effect was much weaker than in nonword processing, where four participants showed significant or highly significant effects in their individual data. Logistic regression analyses were carried out to compare accuracy across the two tasks. JW, TDS and TVR showed no difference in the effect of contrast type on accuracy between nonword and word discrimination. Both AL and JWh showed a highly significant difference in the effect of contrast type, including both initial and final contrasts, on accuracy (logistic regression p <.001**). However, this probably reflected their higher accuracy overall on word discrimination rather than a specific difference in the effect of contrast type. When data were analysed for the group, this showed a significant interaction between lexicality, contrast type and participant (logistic regression p <.001**).

Analysis of aphasic reaction times revealed almost no influences of contrast type in either syllable-initial or syllable-final position (see Table 42). The only participant to show any effect was JW. Post hoc tests revealed that his responses to initial voice contrasts were significantly slower than his responses to both two-feature and manner contrasts.

Word Discrim	AL		JW		JWh		TDS		TVR	
	I	F	I	F	I	F	I	F	I	F
Voice I(n=8) F(n=8)	1452	1314	1166	726	670	785	1962	1953	1038	907
Place I(n=4) F(n=12)	2217	1476	539	834	410	819	1859	2496	726	936
Manner I(n=12) F(n=4)	1689	1832	419	566	201	469	1553	2189	913	1036
2 Features I(n=8) F(n=8)	978	1200	280	661	267	391	2106	2335	788	776
ANOVA Sig.	.372	.652	* .027	.797	.115	.192	.813	.855	.250	.415

Table 42. Effects of contrast type on aphasic participants' reaction times (ms) in word discrimination, analysed separately for initial and final contrasts.

Repeated measures tests were carried out to compare the effect of contrast type on aphasic reaction times between nonword and word discrimination. These did not reveal any significant differences in the effect across the two tasks for four of the participants (repeated measures $p > .14$). Only JW showed a trend towards a difference in effect for contrasts in syllable-initial position (repeated measures $p = .077$). It was surprising that no other significant differences in the effect were found, given that some participants showed apparent differences in the distribution of reaction times according to contrast type across the two tasks. However, as discussed above, the power of the analysis was limited by the small number of cases of each contrast type available for comparison. This in combination with the variability in aphasic reaction times made it difficult to show significant effects on reaction times.

The aphasic participants differed from the controls in showing effects of contrast type in syllable-initial position. Indeed, while the controls showed no effect, the aphasic participants showed the strongest effects of contrast type on accuracy in syllable-initial position. However, in syllable-final position their results were more similar, with place contrasts producing both the slowest responses for controls and the most errors for aphasic participants. For the aphasic group, it seems that those contrasts that participants had difficulty encoding in nonwords (mainly place and voice) also resulted in errors in word discrimination. This indicates that reliance on lexical/semantic representations is not foolproof if faulty phonological encoding prevents reliable access to the lexical and semantic systems. However, the overall greater accuracy that some of the aphasic participants showed in word discrimination does suggest that access to these levels of representation improves performance. Whether this facilitation operates through feedback from higher levels to phonological encoding processes, or through assisting with some other aspect of the task demands (such as attention or memory) cannot be determined from the data. This might be clarified by varying the experimental method. For instance, by varying the inter-stimulus intervals it would be possible to determine how far discrimination abilities are affected by decay, and whether representations of words are more resistant to deterioration than representations of nonwords. Alternatively, the discrimination task might be carried out under divided attention conditions (by introducing a second non-linguistic task such as tapping a rhythm to be carried out at the same time) to explore how far discrimination of words and nonwords is influenced by attentional factors. Both of these experiments would be useful in future research.

General Discussion

In summary, this experiment sought to answer two main questions. These were whether the discrimination of phonetic contrasts is influenced by the lexical status of the contexts in which they are heard, and whether contextual influences are similar for control and aphasic listeners. It was found that lexical status did affect phoneme discrimination, and that some of these effects were different for control and aphasic participants. Controls showed similar patterns for both nonwords and words, in that they responded fastest to initial contrasts, slower to same pairs, and slowest to final contrasts. This was interpreted as showing that controls made similarity judgements at phonetic or phonological levels for both nonwords and words. Whereas in nonwords controls showed effects of contrast type on reaction times for both syllable-initial and syllable-final contrasts, in words the effect of contrast type was only apparent for final contrasts. This was interpreted as suggesting that lexical activation of the second item in the word task was cued by the first word in the pair, but that lexical selection was strongly reliant on processing of the acoustic signal. Aphasic listeners tended to discriminate contrasts more accurately in words than nonwords. They showed similar effects to the controls of match and position on reaction times in nonwords, but showed little effect of contrast position on either accuracy or reaction times in words. This was interpreted as suggesting that their judgements were made primarily at phonetic or phonological levels for nonwords, but showed influences of lexical or semantic levels for words. The aphasic participants showed different effects of contrast type on accuracy dependant on the syllable position of contrasts. They tended to make more errors on voicing contrasts in initial position, but on place contrasts in final position. This pattern was similar for both nonwords and words, suggesting that accuracy on both tasks was affected by phonological encoding difficulties.

One limitation of this experiment is that only CVC syllables were tested, such that in the word items the word uniqueness point always coincided with the word offset. There is clear evidence in the literature that word recognition is influenced by the point in the temporal unfolding of the word at which the uniqueness point is reached (see chapter one). Therefore, the effects of acoustic-phonetic, lexical and semantic representations on phoneme discrimination might conceivably be different before and after a word's uniqueness point is reached. For instance, it might be predicted that the effects of word meanings on reaction times might be greatest, and the effects of phonological encoding weakest, for that portion of a word that occurs after the uniqueness point. This hypothesis might be tested by comparing phoneme discrimination in words and nonwords, using a wider range of phonological structures and uniqueness points in the sets of stimuli.

It was claimed in chapter four that aphasic listeners who are unable reliably to access word meanings on the basis of information flow from the acoustic signal may show greater effects of contextually activated semantic representations on lexical access than do normal listeners. This hypothesis was discussed in relation to the findings that the lexical advantage in lexical decision was greater when words followed a predictive sentence context than when they were presented in isolation, and that aphasic listeners who responded faster to single words with small neighbourhoods showed no effect of neighbourhood density for words in sentence contexts. It was argued that this difference may have indicated greater reliance on phonological representations in simple lexical decision, and greater reliance on other levels of representation (such as contextual semantics) in the sentence task. This hypothesis is also relevant to considering the effects of lexicality on phoneme discrimination that have been demonstrated in this second experiment. An issue that remains unresolved is whether the effects of lexical status on phonological encoding that have been described here arise primarily from the influence of lexical or semantic representations. When participants hear a word, activation of both lexical and semantic representations usually takes place automatically, and within a short enough time-course to influence the processing measured in this experiment. It has been suggested that some of the differences found between controls and aphasic listeners in the effects of lexicality may be due to the greater reliance on semantic representations in aphasic discrimination judgements. However, this hypothesis is tentative since the actual activation of lexical and semantic representations in this task remains concealed. A further experiment was therefore designed to explore more explicitly the relationship between phonological encoding, lexical access, and semantic representations activated by pictures. The results of this experiment will be described in the following chapter, including evidence that some aphasic listeners' phonemic judgements are heavily influenced by semantic context.

Chapter 6 Effects of picture contexts on phoneme discrimination

Introduction

The findings of experiment two revealed clear influences of lexicality on phoneme discrimination for both control and aphasic participants, but left some uncertainty as to the representational levels producing these effects. When listeners hear a word, both phonological and semantic representations are automatically activated. Thus the effects of lexicality on phoneme discrimination may have arisen from phonological or semantic level processing mechanisms. This distinction is important to understanding the findings in relation to theoretical models of auditory processing, since a key difference between models is the degree to which higher level representations might influence phonological encoding. In order to clarify which representational level/s exerted an effect on phoneme discrimination, a task should examine the effect of semantic factors on processing separately from effects of lexical factors.

It has been clearly established in the literature that semantic context influences spoken word recognition. Recognition is facilitated by highly congruent semantic contexts, and hindered by incongruent contexts. It has also been demonstrated that lexical representations influence phonological encoding, with ambiguous phonemes perceived as belonging to categories that form words rather than nonwords (see chapter one for a review). It has been suggested that some aphasic listeners may rely heavily on semantic contexts to compensate for their impaired auditory processing abilities (e.g. Saffran, Marin, & Yeni-Komshian 1976). If this is the case, it might be predicted that semantic contexts would have a greater effect on the auditory processing of aphasic than control participants. Most reported studies of semantic context effects have utilised linguistic contexts such as single word or sentence primes. Such linguistic contexts provide reliable evidence of the influence of semantic contexts on processing by normal listeners, but the evidence is less clear in the case of aphasic listeners. This is because these paradigms rely on participants accessing the semantic representation of the prime word or sentence accurately. All of the aphasic participants in this study revealed some degree of difficulty in accessing semantic representations from spoken words in their performance on Spoken Word to Picture Matching and/or Auditory Synonym Judgment, as well as difficulty understanding sentences on the Test for the Reception of Grammar. It is therefore difficult to be certain that target semantic representations would be reliably activated by word or sentence primes for these participants.

An alternative processing route to semantic representations, that bypasses these participants' impaired linguistic processing, may be provided by the use of pictures. Pictorial contexts may thus provide a more reliable means than linguistic primes of assessing semantic context effects on processing by aphasic listeners. However, this assumption is not straightforward since a number of aspects of visual processing may also be impaired following stroke or other brain injury. Impairments that have been reported in the literature include cortical blindness, hemianopia, visual field neglect and visual agnosia (see Ellis & Young 1996 chapters 2 and 3 for a review). The ability of each of the aphasic participants in this study to process picture stimuli was therefore assessed to establish whether pictures would provide a reliable means of activating semantic representations. The Birmingham Object Recognition Battery object decision subtest was used to explore participants' recognition of simple pictures, while the Pyramids and Palmtrees test (three picture version) explored their ability to make semantic/pragmatic judgments about the relatedness of pictures. In addition, both the Spoken- and Written Word to Picture Matching tests include a visual distractor in the array for each word. The results of these assessments (discussed in chapter three) indicated that JW, JWh and TDS are reliably able to access semantic representations from pictures. TVR probably also has normal picture processing abilities (although his performance on the BORB object decision test was difficult to interpret), while AL may exhibit a mild deficit in picture processing

A picture-word verification task was developed to provide a method of explicitly exploring the influence of semantics on auditory processing. Participants were presented with a picture that remained in view until a response was recorded. A spoken word was presented that either named the picture or differed from the name by one phoneme, and participants were instructed to decide whether the word and picture matched. This task is similar to that developed by Howard & Franklin (1988, p.47). However, the two tasks differ in that a) Howard & Franklin's task only tested word final contrasts, whereas in this task both initial and final contrasts were presented, and b) the effects of contrast type were not explored by Howard & Franklin. This experiment was designed to explore three main questions. The first is whether phoneme discrimination is influenced by the semantic context provided by a picture. If the picture context does influence discrimination, a second question is whether these effects are different to those created by a lexical context. This task contrasted the same word-pairs as were tested in the word minimal pair discrimination task, thus ensuring that the same phonetic contrasts were tested across all three tests of phoneme discrimination. Comparison between performance on this task and performance on the two minimal pair tasks makes it possible to explore the relationship between access to semantic representations and the discrimination of phonemic contrasts. If there is no difference in the effects of the lexical and pictorial contexts on phoneme discrimination, this might suggest that the effects of lexicality revealed through comparison of nonword and word discrimination results arose from access to semantic representations when participants heard words. If, on the other hand, different effects of lexical and picture contexts emerge, this might suggest that the lexicality effects found in minimal pair discrimination resulted from processing mechanisms at the word-form rather than the semantic level. Finally, this experiment sought to establish whether any influences of a pictorial-semantic context on phoneme discrimination would be similar for control and aphasic listeners.

Method

Participants

A group of five aphasic listeners and a group of ten controls took part in the experiment. The five aphasic participants were the same individuals as profiled in chapter three (Table 1), and whose results were presented in chapters four and five. The ten control participants were the same group as described in chapter four (Table 7), and whose results were presented in chapters four and five.

Stimuli

There were one hundred and twenty-eight items, each consisting of a picture paired with a word. In half the items the word named the picture (e.g. a picture of a *goat* with the word *goat*), while in the other half the word was a minimal pair of the picture name (e.g. a picture of a *goat* with the word *coat*). Word stimuli were the same recorded tokens of words that had been used in the word minimal pair discrimination task. For each word a corresponding picture was developed that provided a straightforward match[36], such that the word named the picture. Each picture was used twice, once paired with a matching word and once with a non-matching word.

Procedure

General procedures for stimulus recording, task presentation and recording of responses were as described in chapter four for the lexical decision experiment. Items were presented over two testing sessions, with each picture presented once per session. Half the pictures in each session were presented with a matching word and half were presented with a non-matching word. Pictures were presented in the centre of the computer screen against a white background. Participants were instructed to take time to look at each picture as it appeared on the screen before pressing the 'Go' button to initiate presentation of the spoken word. Participants were instructed to judge whether the word and picture matched each other. A delay of one second was built in between depression of the 'Go' button and presentation of the spoken word

[36] It was subsequently found that the pictures related to one word-pair (seed and feed) were ambiguous, resulting in slower responses and a higher rate of errors than other items. Responses to these items were excluded from analysis due to a number of participants expressing uncertainty about these pictures. However, where the exclusion of these items resulted in insufficient cases being available for analysis of the effect of initial contrast type for individual participants, they were retained. Such exceptions are made clear in presentation of the results, and conclusions based on these statistical tests remain cautious.

to ensure that participants would have seen the picture prior to hearing the word. Responses were made by pressing one of the two response buttons. These buttons were labelled:

☑ ☒

yes **no**

Once the participant had made a response the picture was automatically removed from the screen. The next picture appeared on the screen after a 200-millisecond delay. Accuracy and reaction time data were recorded and prepared for analysis as described in chapter four.

Results

Controls all performed at or close to the ceiling of this task. The mean score was 98% (range 98-100% raw score range = 124/128-128/128 SD = .127). No further statistical analyses of accuracy were carried out for control data. Aphasic participants all scored below the range of the controls (AL 89%, JW 82%, JWh 95%, TDS 93%, TVR 92%). The aphasic group showed a mean score of 88% (aphasic range = 82-95% raw score range = 103/125-122/128 SD = .296). The overall accuracy of the aphasic participants on this task was compared to their accuracy on word discrimination. Four of them achieved higher scores overall in word discrimination than picture-word verification. This difference was significant for AL and TVR (logistic regression for AL p =.044*; TVR p =.017*) and approached significance for JW (logistic regression p =.093). The difference was not significant for JWh who was close to ceiling on both tasks. Interestingly, TDS differed from the other aphasic participants in that he was more accurate overall on picture-word verification than on word discrimination (logistic regression p =.018*). It was demonstrated from his performance on both Written Synonym Judgement and

Pyramids and Palmtrees that TDS has relatively intact semantic representations, and that he is able to access these from pictures (see chapter three). It was also suggested in chapter four that he may make greater use than normal listeners of contextually activated access to the semantic representations of words as a result of his difficulties in phonological encoding. Thus his superior performance on picture-word verification compared to word discrimination may be an indication that his auditory processing is enhanced by the availability of pictorially-activated semantic representations. This enhancement may have been greater for TDS than for the other aphasic participants, since none of them scored within normal limits on both Pyramids and Palmtrees and on Written Synonym Judgement. The difference in overall accuracy between word discrimination and picture-word verification was highly significant for the group as a whole (binary logistic regression p<.001**).

It is interesting that four of the aphasic participants made more errors on picture-word verification than on word discrimination, given that pictures are widely believed to facilitate aphasic language processing. Some of this difference in aphasic performance between the two tasks might be due to attentional factors. The different task demands of word discrimination and picture-word verification will certainly influence aphasic participants' attention during listening. While in the discrimination task attention is directed primarily to phonological forms, in picture-word verification participants must attend explicitly to word and picture meanings. According to the findings of Hugdahl et al. (2003, see chapter one), this difference in attention would result in different anatomical areas of activation during the two tasks. It might be expected that the word discrimination task, like Hugdahl et al's word listening condition, would result in a leftward asymmetry of activation. Since their study did not include an explicit semantic condition, their findings do not predict which areas would be activated in the picture-word verification task. However, findings of other studies have shown that pictures produce bilateral activation dispersed over many cortical areas, commencing in occipital regions and spreading to parietal, temporal and frontal regions (e.g. Levelt et al. 1998). This might partially explain why semantic representations activated by pictures have a greater effect on lexical selection in aphasic listeners than controls. If lexical selection processing is primarily localized in areas of the left hemisphere that are damaged in these participants, then unimpaired bilateral occipital and right temperoparietal areas might have greater influence on their decision making. Whilst this is conjecture, it is an interesting possibility that some of the differences in performance between the two tasks may be related to attention-modulated differences in brain activity. Another possible source of the difference in accuracy is the greater complexity of the picture-word verification task, since participants might have difficulty in integrating inputs from the two different modalities. For instance, if a picture of a goat activated semantically related but inappropriate word-forms (such as 'sheep'), this could lead the participant to incorrectly reject the word 'goat'. A difficulty of this sort would result in errors on both matching and non-matching items. An alternative explanation is that errors would occur through participants relying on the semantics of the picture to activate or select lexical items when their phonological encoding was ineffective. If this were the case, it would be expected that most errors would involve the non-matching items. For example, the semantic representation activated by the picture of a goat should most strongly activate the word-form 'goat'. If phonological encoding were insufficient to determine whether the spoken word was 'goat' or 'coat', the semantically driven activation of the 'goat' word-form would increase the likelihood of the spoken word being identified as 'goat'. This could occur through shifting of the decision boundary between /g/ and /k/, such that more exemplars would fall into the /g/ category. These possibilities are considered further in discussion of the effects of match and of contrast type.

Position and Match

Responses to words that differed in the initial consonant from the word related to the picture were compared with responses to those that differed on the final consonant. The control group showed no effect of the position of the contrast in the syllable on their reaction times (ANOVA $p = .338$) (see Table 43). There was a highly significant effect of participant (ANOVA $p < .001$**), and no interaction between position and participant (ANOVA $p = .885$).

	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
Same (n=64)	343	762	484	542	566	325	383	364	501	620
Differ (initial) (n=32)	474	853	503	775	663	357	420	477	520	685
Differ (final) (n=32)	490	880	617	801	646	391	495	402	521	654

Table 43. Controls' mean reaction times (ms) to same pairs and to pairs with syllable-initial and syllable-final contrasts in picture-word verification.

This result was clearly different to that found on word discrimination, where the control group had responded significantly faster to initial than final contrasts. Repeated measures tests were carried out to compare the effect of position between the two tasks. These revealed a highly significant difference in the effect of position on controls' reaction times (repeated measures context x position $p < .001^{**}$). This interaction was not influenced by the differences between individual participants in overall speed of processing (repeated measures context x position x participant $p = .533$). The difference in the effect of position between the tasks was interpreted as reflecting differences in the levels of representation at which participants made their decisions. In the word discrimination task, participants could potentially make the same-different judgment at phonetic, phonological or semantic levels. The effect of contrast position suggested that decisions were made at either phonetic or phonological levels, which are both temporally encoded. The picture-word verification task requires that the decision is made at the level of semantic representations. Since semantic representations are not temporally encoded, the position of the contrast in the syllable did not influence reaction times on this task.

This interpretation nevertheless requires further consideration. It is not suggested that the different tasks limit the levels of representation that are activated to those at which the decision is made; indeed, it is assumed that in both tasks, representations are automatically activated at phonetic, phonological and semantic levels as participants listen to the stimuli. Rather, it is suggested that the specific task demands serve to focus the participants' attention to a greater degree on one or other level of representation. In chapter one, evidence was presented that attention to different levels of representation whilst listening to speech results in different areas of neuronal activation, even when the actual stimuli are the same (Hugdahl et al, 2003). Thus it might be predicted that the same words heard under the two task conditions in these experiments would generate different patterns of activation, corresponding to the relative strength of activation at phonetic, phonological or semantic levels of representation.

Responses to words presented with a matching picture were then compared to responses to words presented with a picture that matched the minimal pair of that word. For instance, responses to items such as the word 'goat' presented with a picture of a goat were compared to responses to items such as the word 'coat' presented with the same picture. Since there was no effect of position on reaction times, both initial and final contrasts were combined in the set of non-matching items for this analysis. The results revealed a highly significant effect of match, with faster reactions to matching items than to non-matching items (ANOVA $p = .001^{**}$) (see Table 43). There was a highly significant effect of participant (ANOVA $p < .001^{**}$), and no interaction between match and participant (ANOVA $p = .105$). The effect of match on controls' reaction times may have arisen since it takes longer to rule out than to recognise a semantic relationship between the picture and the word. This is because there are many possible semantic relationships between a word and picture. For instance, a picture of a coat may activate semantic and phonological representations for *coat, jacket, clothing, warm, hood, sleeves* as well as many others[37]. The listener must compare whole networks of semantic representations generated by the word and the picture before concluding that they do not match, whereas matching items might be identified on the basis of overlap in a small number of core semantic attributes.

No direct comparisons of the effect of match between word discrimination and picture-word verification tasks were made because of qualitative differences in this

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[37] In future research it would be useful to present the picture stimuli in a naming task to a control group, in order to determine how often the pictures evoke the intended target, and to what extent participants agree in their naming responses. Pictures that show low levels of agreement on the intended target could be replaced with less ambiguous alternatives.

factor. In the minimal pair discrimination tasks, the participant must decide whether two spoken syllables are the same or different, with all the information necessary to the decision making process available within the acoustic signal and the phonological system. The factor of *match* in picture-word verification is qualitatively different, since the participant must decide whether two representations of entirely different natures correspond to each other conceptually. This cannot be done on the basis of the acoustic and visual signals themselves, but necessitates that these input signals activate conceptual-semantic representations and that these internally generated representations are compared with each other.

None of the aphasic participants individually showed an effect of contrast position on accuracy of response (see Table 44). Although JW and JWh made a greater number of errors on final than initial contrasts, this difference was not significant for either of them (chi square for JW $p = .138$; for JWh $p = .162$). AL, TDS and TVR all made similar numbers of errors in initial and final positions (chi square $p > .3$). This pattern was similar to that found on word discrimination, where none of the aphasic participants had shown an effect of position on accuracy. Logistic regression analyses were carried out to statistically compare these effects between word discrimination and picture-word verification. Only JW showed any significant difference in the effect of position between the two tasks (binary logistic regression position x context $p = .026$*). This was surprising, since individual patterns did appear to show differences in effect. JW and TDS both made more errors on initial contrasts in word discrimination than picture-word verification, while conversely AL, JW and JWh all made more errors on final contrasts in picture-word verification than word discrimination. However, when the comparison was made for the whole group there was a highly significant difference in the effect (binary logistic regression position x context $p < .001$**). In word discrimination, mean accuracy for the group was greater for final contrasts (85%) than initial contrasts (79%). This pattern was reversed in picture-word verification, with greater accuracy on initial contrasts (91%) than final contrasts (86%). These findings are in accordance with those of Gardner, Albert & Weintraub (1975), who showed in a comprehension task that aphasic listeners tended to confuse words with different endings rather than different onsets (see chapter one). Thus it appears that the picture context in the current study may have some facilitatory effect on accuracy of phonological encoding, but inhibit accurate selection between competing lexical candidates. This will be discussed further below.

	AL		JW		JWh		TDS		TVR	
	A	RT	A	RT	A	RT	A	RT	A	RT
Matching (n=64)	93% (n=61)	1933	88% (n=63)	697	98%	1198	91% (n=63)	4049	91%	2292
Different (initial) (n=32)	86% (n=30)	2109	84% (n=31)	1481	97%	1324	97%	3556	91%	2187
Different (final) (n=32)	81% (n=31)	2895	68% (n=31)	1609	88%	1369	94%	3693	97%	2205

Table 44. Aphasic participants accuracy and mean reaction times (ms) to same pairs and to pairs with syllable-initial and syllable-final contrasts in picture-word verification

When reaction times were examined, four of the aphasic participants showed no effect of contrast position in picture-word verification (ANOVA $p > .6$) (see Table 44). Only AL showed any effect of position, with faster reactions to initial than final contrasts (ANOVA $p = .014$*). The effect of contrast position on reaction times was compared between the two tasks. Three of the participants showed no difference in the effect of position suggesting that judgements were made primarily at the semantic level in both tasks (repeated measures context x position for JW $p = .671$; TDS $p = .608$; TVR $p = .911$). The two remaining participants showed a trend towards a difference in effect. JWh had shown a trend towards an effect of position in word discrimination, but not in picture-word verification (repeated measures context x position $p = .08$). It was argued in Chapter Five that she was able to encode words accurately in word discrimination, and like the controls did not need to rely on semantic representations in making the same-different judgment. However, since the picture-word verification task required semantic judgments, JWh showed no effect of contrast position on her reaction times in this task.

AL, in contrast, had shown no effect of position on his reaction times in word discrimination, but did respond faster to initial than final contrasts in picture-word verification (repeated measures context x position p =.051). Under the account of position effects given above, this would suggest that he was making the judgment in picture-word verification not based on semantics, but at a temporally encoded level which might be phonetic or phonological. This would differ both from the other aphasic participants and the control group and so needs to be accounted for. One possibility is that the pictures activated phonological word-forms, and that his decisions were based on comparison of these phonological representations with the spoken words. This account would assume that AL was able to access picture names, at least internally. On Spoken Picture naming AL did produce a spoken response to all items, albeit incorrect and imprecisely articulated. Although none of these responses appeared related to the target, AL made no attempts to self-correct and showed no awareness of his errors. This seems to suggest that he does internally activate phonological forms of some sort in response to pictures. How far his errors on Spoken Picture Naming were due to impaired activation of lexical forms, and how far they were due to post-lexical output problems (such as motor-speech processes) is difficult to discern. This uncertainty regarding AL's ability to activate picture names internally, as well as the suggestion that he may have mild visual processing difficulties (see chapter three) makes it difficult to evaluate the hypothesis that his judgments in picture-word verification might have been based on comparisons at the phonological level. To determine whether such a strategic difference might occur within normal processing patterns, the effect of position on control's reaction times was analysed individually. While nine of the controls showed no effect of position, DT did show a trend towards faster responses to initial than final contrasts in picture-word verification (ANOVA p =.057). This raises the possibility that some participants may attend more strongly or make decisions at a phonological level even on an overtly semantic task. This is consistent with the notion discussed earlier in relation to findings of Hugdahl et al (2003) that performance on such tasks is influenced by attentional factors. Individuals' attention to specific levels of representation may largely be determined by the task demands, but also be susceptible to individual factors such as a participant's strategic approach to the task.

Accuracy of response to matching and non-matching items was then compared (see Table 44). Three of the aphasic participants made more errors on non-matching items, with this effect approaching significance (chi square for AL p =.088; JW p =. 055; JWh p =.094). TDS and TVR showed no effect of match on accuracy (chi square p >.25). These results are relevant to considering the two accounts suggested above to explain aphasic participants' overall lower level of accuracy on picture-word verification compared with word-discrimination. The first account given was that it resulted from the greater task complexity of picture-word verification, which would result in errors on both matching and non-matching items. This account was supported by TVR's and TDS's data, since their errors were evenly distributed between matching and non-matching items. It has already been suggested that TVR's errors on the minimal pair discrimination tasks reflected difficulty with other aspects of auditory processing, such as attention or memory, rather than a specific phonological encoding difficulty. If this is correct, it is likely that such an impairment would also result in task related difficulties in picture-word verification. For instance, a difficulty in attending to the auditory input while looking at the picture could result in errors dispersed across matching and non-matching items. TDS, on the other hand, did show clear evidence of a specific phonological encoding difficulty on both the minimal pair discrimination tests. However, at least three of TDS's errors on the matching items in picture-word verification were certainly due to factors other than phonological encoding. For instance, whilst looking at the picture of a coat whilst hearing the matching word 'coat', TDS told the researcher that they did not match because the coat in the picture had a hood i.e. he rejected the match on semantic grounds. Similarly, he explained that he had rejected the matching item *pork* because he thought the picture of a pork chop looked like a lamb chop. So, although the source of their errors may have been different, both TDS and TVR appeared to make errors related to the task demands. The second account of errors on picture-word verification was that errors on the non-matching items could have arisen from reliance on picture-activated semantics when phonological encoding was impaired. This account is in accordance with the data of AL, JW and JWh, since they made more errors on the non-matching items, and is considered further below in relation to the effects of contrast type on accuracy.

The effect of match on aphasic reaction times was then considered (see Table 44). Since there was no effect of position on reaction times for four of the aphasic participants, response latencies to both initial and final contrasts were analysed together for these participants for comparison to the matching items. JW showed a highly significant effect of match, with faster responses to matching words and pictures (ANOVA $p < .001^{**}$). As with the controls, this may reflect the longer processing time required to rule out than to recognise a semantic relationship between the two representations. For instance, one item included a picture of a *mouse* presented with the word *mouth*. While the word does not name the picture, there is nevertheless some conceptual-semantic association since a mouse does have a mouth. A judgement must be made as to whether the association is strong enough to respond that the two items match, which may take longer than deciding that the word *mouse* matches the picture of a mouse. In contrast, JWh, TDS and TVR showed no effect of match on speed of response (ANOVA for JWh $p = .112$; TDS $p = .804$; TVR $p = .677$). This might reflect strategic factors, for instance that these aphasic participants lacked confidence in their decisions, and so were more hesitant than the controls in giving positive responses. The effect of match on AL's reaction times was analysed separately for initial and final contrasts, since he had shown an effect of position. He showed no difference in speed of response to matching items and initial contrasts (ANOVA $p=.320$), but responded faster to matching pairs than to final contrasts (ANOVA $p < .001^{**}$). Like the controls, AL was generally faster to recognise than rule out a semantic match.

Contrast

The set of items in which the picture and word did not match was balanced across four sets, based on the type of phonetic contrast by which the word differed from the picture name. This allowed analysis of the influence of phonological encoding on processing in the picture-word verification task. As in the nonword and word discrimination tasks, the effect of contrast type was explored separately for contrasts in initial and final position.

For contrasts in word-initial position there was no effect of contrast type on controls' reaction times (ANOVA p =.161), but a highly significant effect of participant (ANOVA p <.001**) (see Table 45). Although there was some individual variation in patterns of reaction times across the contrast types, there was no significant interaction between contrast and participant (ANOVA p =.696). Given that word onsets are most important for the activation of lexical candidates, this result suggests that factors other than the acoustic-phonetic signal were influencing lexical activation. The only other available source of activation was the picture, thus the strong semantic and lexical activation that this generated may have outweighed subtle differences in processing speed for different types of phonetic contrast.

Initial contr.	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
2f (n=8)	603	880	494	763	682	427	378	404	420	593
M (n=12)	503	1017	494	898	657	412	439	487	568	682
P (n=4)	102	859	723	352	397	212	546	190	309	888
V (n=8)	351	619	471	707	721	213	405	607	606	728

Table 45. Controls' mean reaction times (ms) to types of phonetic contrast in word-initial position in picture-word verification.

This pattern was similar to that found in word discrimination, where there was also no effect of contrast type on controls' reaction times to word-initial contrasts. The effect of contrast type was compared between the word discrimination and picture-word verification tasks. This revealed an overall difference in reaction times between the two tasks, with faster responses to word discrimination (repeated measures p<.001**). This is likely to reflect the greater processing time required for activating and comparing conceptual-semantic representations in the picture-word verification task, than comparing two phonological forms in the discrimination task. However, there was no difference in the effect of contrast type for word-initial contrasts between the two tasks (repeated measures p =.262).

This similarity between the effect of contrast type in the two tasks may mean that the top-down influence on initial contrast discrimination seen in judgment of word-pairs was driven by the semantic representation of the first word in the pair, rather than by its phonological form. Alternatively, it may be that different levels of representation influenced activation in the two tasks (phonological in word discrimination and semantic in picture-word verification), but that any contextual influence on lexical activation masks differences in speed of phonological encoding in a similar way. It might be possible to test these two accounts through a phoneme discrimination task in which words were balanced for both imageability and neighbourhood density. If the facilitatory effect were driven by semantic representations in both tasks, then it might be predicted that both tasks would produce stronger effects for high than low imageability words. If, however, the facilitation was driven by phonological word-forms in the word discrimination task, then it might be predicted that neighbourhood density would have a stronger effect on performance on that task than on picture-word verification. Any interactions between imageability, neighbourhood density, and phoneme discrimination, would illuminate the degree to which different levels of representation influenced responses in each task.

Controls did however show a strong effect of contrast type on speed of processing contrasts in word-final position (ANOVA $p <.001^{**}$) (see Table 46). Post hoc Tukey tests revealed that responses to both manner and two-feature contrasts were faster than responses to both place and voice contrasts. There was also a highly significant effect of participant (ANOVA $p <.001^{**}$), and no interaction between contrast and participant (ANOVA $p =.969$). This pattern was very similar to that found in word discrimination, and also reflected the rank order of reaction speed to the different contrast types in nonword discrimination. It was argued earlier that word offsets are of greatest importance for selection between competing lexical candidates, at least in monosyllabic words. The influence of the type of phonetic contrast suggests that selection is driven more strongly by features of the auditory input than by the semantic context, even in an overtly semantic task. Some support for this claim comes from the results of experiment one. The results of Sentence Lexical Decision showed that controls made very few errors overall, with no statistical difference in error rates for words and nonwords. This showed that controls were accurate in word recognition even when the semantic context might have biased their judgments. The results of both these experiments seem to indicate that normal speech perception is resistant to contextually induced errors of lexical selection.

Final cont.	AT	DB	DT	GH	JH	JS	MC	RM	SF	WB
2f (n=8)	352	835	552	717	578	322	366	334	536	549
M (n=4)	350	867	618	506	571	245	443	358	470	655
P (n=12)	625	883	639	862	615	467	575	432	574	716
V (n=8)	512	928	647	959	799	427	543	456	445	667

Table 46. Controls' mean reaction times (ms) to types of phonetic contrast in word-final position in picture-word verification.

The effect of contrast type was compared between the word-discrimination and picture-word verification tasks. As found for word-initial contrasts, this revealed an overall difference in reaction times between the two tasks, with slower responses to picture-word verification reflecting the additional processing time required to activate semantic representations (repeated measures $p<.001$**). There was no difference in the effect of contrast type between the two tasks (repeated measures $p<.437$).

The effect of contrast type on overall accuracy (including all items) was then considered for the aphasic participants. This was highly significant for AL, JW and JWh, but not for TDS or TVR (see Table 47).

Contrast	AL	JW	JWh	TDS	TVR
Voice (n=16)	94%	87% (n=15)	100%	94%	100%
Place (n=16)	53% (n=15)	25%	75%	88%	88%
Manner (n=16)	87% (n=15)	93% (n=15)	100%	100%	94%
2 Features (n=16)	100% (n=15)	100%	94%	100%	94%
Chi Square Sig.	** <.001	** <.001	** .001	.443	.705

Table 47. Effects of contrast type on aphasic participants' accuracy in picture-word verification

Analysis of the effect of contrast type on aphasic responses to word-initial contrasts proved to be problematic. This was because, following exclusion of the four items related to the seed/feed contrast (see footnote three of chapter two), at most one or two cases of initial place contrasts remained in each participant's data set. This prevented statistical comparisons of accuracy and reaction time between the different types of contrast for some participants, and reduced the power of the statistical tests that could be carried out. It was however considered essential to examine the influence of phonetic factors in word-initial position, given the importance of word onsets for revealing lexical activation processes. In order to maximise reliability the analyses were therefore carried out in several ways, the results of which were considered jointly.

For contrasts in initial position, analysis of response accuracy was first carried out with the seed/feed items included to provide sufficient power (see Table 48). This revealed a highly significant effect of contrast type on JW's accuracy, with no correct responses to initial place contrasts. AL, JWh and TDS all showed a trend towards an effect of contrast type, and they too showed most difficulty with place contrasts. However, it is impossible to be certain whether these errors reflected difficulties with encoding the place contrasts, or were due to shortcomings in the picture stimuli. The analysis

Picture-Word Verification	AL		JW		JWh		TDS		TVR	
	I	F	I	F	I	F	I	F	I	F
Voice I(n=8) F(n=8)	88%	100%	88%	86% (n=7)	100%	100%	100%	88%	100%	100%
Place I(n=4) F(n=12)	50% (n=3)	58%	0%	33%	75%	75%	75%	92%	75%	92%
Manner I(n=12) F(n=4)	92% (n=11)	75%	100% (n=11)	75%	100%	100%	100%	100%	92%	100%
2 Features I(n=8) F(n=8)	100%	100% (n=7)	100%	100%	100%	88%	100%	100%	88%	100%
Sig.	.091	* .047	** .000	* .010	.065	.330	.065	.700	.555	.632

Table 48. Aphasic participants' accuracy to types of phonetic contrast in initial and final positions in picture-word verification (including seed/feed items)

of accuracy was therefore repeated excluding the seed/feed items. Both AL and JW showed significant effects of contrast type (chi square for AL p =.025*; JW p =.000**). AL made one error on each set of manner and voice contrasts, and responded incorrectly to the one remaining place contrast. JW responded incorrectly to both the remaining place contrasts and also to one of the voice contrasts. As in both the nonword and word discrimination tasks, TVR showed no effect of contrast type (chi square p =.752). It was not possible to analyse JWh's and TDS's accuracy without the seed/feed data since their only errors had been on the excluded items. In summary, these results provide weak evidence to suggest that accuracy of processing word onsets was influenced by phonetic factors for up to four of the aphasic participants.

The effect of contrast type in initial position on reaction times was then considered. First the analysis was carried out including the seed/feed contrasts for each participant (see Table 49). This revealed significant effects of contrast type on reaction times for AL, JWh and TDS. Post hoc Tukey tests revealed that AL's responses were slower to place contrasts than to both two-feature and manner contrasts. For both JWh and TDS responses to place contrasts were slower than responses to all other contrasts. Thus it appeared that these three participants were particularly slow in processing initial place contrasts. In order to reduce the influence that especially slow responses to specific problematic items might have exerted on the distribution of response latencies, the raw reaction times were

Picture-Word Verification	AL		JW		JWh		TDS		TVR	
	I	F	I	F	I	F	I	F	I	F
Voice I(n=8) F(n=8)	2575	3122	1855	1778	1112	1404	3713	5128	1423	2562
Place I(n=4) F(n=12)	4064	3167	765	1307	2501	1359	11798	3584	2184	2078
Manner I(n=12) F(n=4)	1665	3219	1699	1455	1470	1274	3308	3088	2593	2101
2 Features I(n=8) F(n=8)	2102	3620	1046	1935	1220	1399	2729	2712	2434	2089
Sig.	* .010	.947	.112	.501	** .005	.987	** .000	.292	.146	.667

Table 49. Aphasic participants' reaction times (ms) to types of phonetic contrast in initial and final positions in picture-word verification

transformed into their log10 values. The analysis of variance was repeated on each participant's log reaction times with the seed/feed cases included in the data set. This analysis also revealed significant effects of contrast type for AL, JWh and TDS (ANOVA for AL p =.036*; JWh p =.041*; TDS p =.001**). JW also showed an effect of contrast type, but this fell short of significance (ANOVA p =.061). Interestingly, his fastest mean reaction times were to place contrasts, but post hoc tests revealed no subsets of contrast type. TVR showed no effect of contrast type (ANOVA p =.117). So in analyses of both raw and log transformed reaction times, AL, JWh and TDS showed significant effects of contrast type on their reaction times to initial contrasts.

However, it was considered possible that these results might have been an artefact of item-specific difficulties related to the seed/feed pictures. The analysis of variance was therefore carried out again excluding the seed/feed cases. Only TDS showed a significant effect of initial contrast type (ANOVA p =.001*). His slowest response was to place, but post hoc tests could not be carried out since only one case of a place contrast remained in his data. AL and JWh also responded slower to place contrasts, but these results were not significant, and observed power was low. The analysis was therefore repeated with the seed/feed items excluded, but including the data of the whole group (with participant defined as a random factor) to provide more cases for comparison. The group means were fastest overall for two-feature contrasts, followed by manner, then voice, and slowest to place contrasts. This was the same rank order as shown by control group responses to nonword minimal pairs, suggesting an influence of normal phonological encoding processes. However, there was no statistical effect of contrast type for the group (ANOVA $p = .419$). There was a highly significant effect of participant (ANOVA $p = .002$**), and a highly significant interaction between contrast and participant (ANOVA $p < .001$**). This interaction reflected the different patterns for individual participants described above, and made the lack of a main effect of contrast type for the group difficult to interpret. However, when the results of all three analyses of reaction times were considered together, they suggested that three of the aphasic participants showed patterns of phonological encoding of initial contrasts in this task that were similar to normal patterns of encoding in nonwords.

The effect of contrast type on both accuracy and reaction times to initial contrasts may indicate that for these participants, the activation of lexical representations is influenced more strongly by bottom-up acoustic-phonetic information than by the semantic context provided by a picture. This pattern is very different to that found for the control group, who showed no effect of contrast type on responses to initial contrasts in this task. It is perhaps unsurprising though that such a difference should be found. Looking at a picture of an object normally produces automatic activation of phonological representations for compatible names, with this activation taking place rapidly. Levelt, Praamstra, Meyer, Helenius & Salmelin (1998) suggest that the visual percept of the picture is processed and the lexical concept accessed within 150 milliseconds, and that the phonological form of the picture name is specified within 275-400 milliseconds after onset of the picture stimulus. In the current experiment there was a minimum one second delay between onset of the picture and onset of the word, with this delay often being longer (dependant on how quickly participants pressed the 'go' button). Internally generated activation of the picture name would therefore precede onset of the spoken word stimulus by at least half a second for the controls. However, the aphasic participants all have impairments in the ability to generate picture names, as evidenced by their very poor performance on Spoken Picture Naming (see chapter three). These participants may not therefore have reliably accessed the picture name prior to hearing the word. Thus for the aphasic participants, lexical activation may still be initiated by the auditory input and so show the effects of acoustic-phonetic features. However, this interpretation must be cautious given the inclusion of the unreliable seed/feed items in the individual analyses.

The effect of contrast type was then compared between the word minimal pair and the picture-word verification tasks for each participant. No individual participant showed any difference in the effect of contrast type on accuracy of response to initial contrasts between the two tasks (binary logistic regression $p > .5$). This was true both when the seed/feed items were included in the picture-word verification data, and when they were excluded. However, due to the limited number of place contrasts included in these analyses, a whole group analysis was also conducted to increase statistical power. This revealed a non-significant trend towards a difference in the effect of contrast type between the two tasks (binary logistic regression $p = .077$). This difference related mainly to the group's much higher mean accuracy in detection of voice contrasts in picture-word verification (95% correct) than in word discrimination (60% correct). Accuracy was also slightly higher for manner contrasts (97% correct compared to 92% correct in word discrimination). The group however made more errors overall on place contrasts in picture-word verification (55% correct) than in word discrimination (65% correct). Possible reasons for this will be discussed below.

Comparisons were also made of the effect of contrast type on reaction times to initial contrasts between the two tasks, and revealed a number of different patterns. AL, JWh and TDS were all similar in that they had shown no effect of contrast type on reaction times to initial contrasts in word discrimination, but a highly significant effect in picture-word verification. Comparison of the effect of contrast between the two tasks revealed significant differences for both JWh (repeated measures $p = .033$*), and TDS (repeated measures $p < .001$**). AL did not show a significant difference in the effect (repeated measures $p = .264$), but as only one place contrast was available for comparison this result is unreliable. JW's pattern was different. While in word discrimination he had shown a weakly significant effect of contrast type, in picture-word verification there was no effect. Comparison of the effect between the two tasks revealed no difference (repeated measures p= .497). Although TVR showed no effect of contrast type in either task, comparison between the two tasks revealed a trend towards a difference in the effect (repeated measures p =.081). A whole group analysis was carried out to provide increased cases for comparison. The aphasic group showed a highly significant difference in the effect of contrast type between the two tasks (repeated measures p =.004*). Thus several individual participants as well as the whole group showed an effect of the picture context on their speed of processing phonetic contrasts in initial position.

For contrasts in final position, only AL and JW showed significant effects of contrast type on accuracy (see Table 48). Both made most of their errors on final place contrasts (like Tyler's 1992b patient JG), although AL also made errors on manner and JW on both manner and voice contrasts. The other three aphasic participants made few errors overall, although all had some errors on place contrasts. It appeared that place contrasts were producing more errors in aphasic responses, but that this was not shown statistically due to a ceiling effect for several individuals. Response accuracy was therefore analysed for the whole group to provide a greater number of cases, and to test whether there was indeed a common pattern within the group. This revealed a highly significant effect of contrast type, resulting from a substantially higher error rate on place contrasts (chi square p <.001**). This is a very similar pattern to that shown in word-discrimination, where group analysis also revealed a highly significant effect of contrast type with more errors on place contrasts. Results on the two tasks were compared statistically. None of the aphasic participants showed a significant difference in the effect of contrast type on accuracy of response between the two tasks. JWh did show a trend towards a difference in effect (binary logistic regression p =.068), with more errors on place and two-feature contrasts in picture-word verification. A whole group analysis revealed no difference in the effect of contrast type between the two tasks (binary logistic regression p =.876), and suggests that the processes involved in lexical selection were similar in both context conditions.

Analysis of reaction times to word-final contrasts in picture-word verification revealed that none of the aphasic participants showed any effect of contrast type (see Table 49). This pattern differed from the controls, who had shown a highly significant effect of contrast type with faster reactions to two-feature and manner contrasts. This suggests that, unlike the controls, aphasic participants' selection of lexical targets in this task was driven more by semantics than by the acoustic signal. Repeated measures tests were carried out to compare the effect of contrast type on reaction times to final contrasts between the two tasks. None of the aphasic participants showed any difference in the effect (repeated measures $p > .25$). A group analysis was also carried out to test whether greater statistical power would reveal a difference in the effect, but showed no difference (repeated measures $p = .304$). This mirrors the patterns of accuracy across the two tasks, and suggests that processes of lexical selection are similar in both context conditions.

In summary, aphasic group analyses revealed that contrasts in initial position were processed more accurately in picture-word verification, whereas contrasts in final position were processed more accurately in word discrimination. This suggests that picture contexts may influence the processes of lexical activation and lexical selection in different ways for aphasic listeners. For aphasic processing of contrasts in initial position, there were differences between picture-word verification and word discrimination in the effect of contrast type on both accuracy and reaction times. This suggested that word and picture contexts may exert subtly different influences on lexical activation. Several of the aphasic participants made more errors in processing word-final contrasts in picture-word verification than in word discrimination. Such false positive errors suggested reliance on the picture context to guide judgments, whether consciously or not. They also suggest that these participants' lexical selection was more heavily influenced by picture than by spoken word contexts. It is significant that these errors primarily involved place contrasts, suggesting that participants were relying on picture semantics particularly for processing those contrasts that they had more difficulty encoding. Thus the picture-semantic context did appear to exert an influence on aphasic processing that was different from the influence of the word context. This is consistent with the hypothesis that the effects of lexicality on aphasic minimal pair discrimination arose primarily from phonological rather than semantic processing mechanisms.

General Discussion

The main questions to which this experiment was directed were whether phoneme discrimination is influenced by pictorial contexts, whether the effects of pictorial contexts differ from the effects of lexical contexts, and whether such effects are different for control and aphasic listeners. The results have demonstrated a number of key differences both between the performance of control and aphasic participants, and between the effects of word and picture contexts on auditory processing. While pictorial contexts do influence phoneme discrimination, differences in effect were found between control and aphasic listeners. Controls showed little difference in the effects of pictorial and lexical contexts, while aphasic participants showed a number of differences between these two conditions.

Of particular interest in these results was the strong interaction between the type of phonetic contrast in initial position, and the influence of the picture context on aphasic accuracy. Whilst voice contrasts were discriminated more accurately in picture-word verification than word discrimination, the converse was true of place contrasts. It is interesting to speculate as to why this might have occurred. One possible explanation relates to the degree of acoustic variance in the cues to these two features. The cue of Voice Onset Time (VOT), which is the most salient cue to voicing in initial consonants, varies according to speaker characteristics such as dialect and speech tempo. However, there is little variance in VOT according to the vocalic context that follows an initial consonant. This cue is relatively context independent, thus a voicing feature detector can operate within relatively fixed parameters. The acoustic cues to place of articulation, on the other hand, are acoustically much more variable. This is because they depend on formant trajectories at consonant-vowel boundaries, and so vary acoustically according to the vocalic context that follows the contrast. Since the cues to place are variable, a place feature detector must operate within relatively 'fuzzy' parameters. Processing by a feature detector that operates with vacillating boundaries is more likely to be influenced by contextual information than that of a detector with fixed boundaries. Thus processing of place contrasts at the point of categorization might be more susceptible to top-down influence than processing of voice contrasts. Under this account, the context would influence the output of the feature detector rather than the acoustic-phonetic information available to it.

An alternative account might be that contextual information actually alters the acoustic-phonetic information upon which the place feature detector bases its decision. This account assumes greater contextual modulation of cues to place than to voicing, due to the neurophysiology of the auditory system. Discrimination of place contrasts relies primarily on the perception of differences in frequency bands of the acoustic signal. Evidence of the function of efferent auditory pathways was presented in chapter one. This demonstrated that top-down information flow increases cochlear sensitivity to expected frequencies, and reduces sensitivity to unexpected frequencies. The efferent system may therefore provide a neurophysiological mechanism that allows higher levels of processing to shift the perception of ambiguous place contrasts across categorical boundaries, through increasing the frequency response for expected spectral patterns. For the categorical boundary in a voice contrast to be altered would require modulation of temporal encoding, but there is no known top-down processing mechanism that directly alters temporal responses within the auditory system. Thus place contrasts might be more susceptible to top-down influences, such as those created by semantically activated word-forms, than are voice contrasts.

Both of these accounts are conjecture, and cannot be appraised from the data in this study. In addition, an account of the precise mechanisms by which context influences discrimination of voice and place contrasts should take account of the lexically-induced shifts in voicing boundaries demonstrated by Ganong (1980). Further research might elucidate whether place and voice contrasts are indeed differentially influenced by contextual factors. For instance, a variation of Ganong's study might test perception of phonemes created along acoustic continua for voice (/p/-/b/ and /b/-/d/) and place (/p/-/t/ and /b/-/d/). These would be spliced onto endings such that one end of each continuum produced a word and the other end a nonword. Participants would be asked to identify the first phoneme in the syllable, and it would be predicted that phonemes around the category boundary would be identified more often as a phoneme that made a word. The strength of the lexicality effect on the perceptual changeover point for voicing continua could be compared with the effect for place continua. If perception of place contrasts is more susceptible to contextual modulation than perception of voice contrasts, it might be predicted that the lexically-induced boundary shift would be greatest on the place continua. However, even if differences were found, it would not be possible to determine whether these were due to phonological or semantic levels of processing. A second experiment might therefore focus on the influence of picture contexts on perceptual boundary shifts. Phonemes from the same continua used in the adaptation of Ganong's design would be spliced onto endings such that both ends of the continuum produced a word. These words would need to be balanced for factors such as frequency, familiarity and neighbourhood size, and would be presented in random order in the context of pictures. On half the trials the picture would be named by the word at one end of the continuum, and on half the trials the name would be the word at the other end of the continuum. The influence of pictures on the perceptual changeover points for place and voice could be compared. Again, on the basis of the hypotheses above, it might be predicted that pictures would exert a greater influence on the perception of place contrasts. Comparisons could be made between the results of these two experiments, to determine whether there were differences in the perceptual influence of words and pictures. Results of such a study would assist interpretation of the task-related differences in phonological encoding found in the present study.

An important question regarding the patterns of context effects shown by the aphasic listeners in these experiments has not yet been addressed. That is whether these effects result from atypical feedback mechanisms, or whether they reflect the operation of normal feedback mechanisms brought into use when earlier stages of auditory processing are impaired. Although beyond the scope of this thesis, this question is significant as it relates to theories of recovery from aphasia. Evidence was presented in chapter one that suggests normal feedback mechanisms may have been responsible. This evidence comes from Samuel's 1990 study of phoneme restoration effects, which showed that normal listeners make more errors in perception of word endings than word onsets when acoustic information is impoverished by background noise. Further, it has been shown in categorical perception and word-monitoring studies that later-occurring segments are more susceptible than word-initial segments to lexical effects in normal listeners (e.g. Connine 1990; Marslen-Wilson & Welsh 1978). An important implication of such findings is that the stronger effects of context on processing of word-final contrasts by aphasic listeners may reflect the normal strategic processing used when listening conditions are unfavourable as a result of either noise or acoustic ambiguity. One way to determine whether aphasic context effects shown in the current study arose from normal feedback mechanisms might be to repeat these experiments with normal listeners, but to impoverish the phonetic information available in the acoustic signal. This might be achieved for instance through acoustic filtering of the stimuli, or presentation in background noise. If the context effects shown by aphasic listeners reflect normal feedback mechanisms, it would be predicted that normal listeners would display similar processing patterns under these conditions. If the aphasic patterns, on the other hand, reflected atypical processing mechanisms, then normal listeners should not produce the same effects even with impoverished acoustic input. It might be illuminating to vary the signal-to-noise ratio to see at what point, if any, normal listeners began to behave like aphasic listeners. Such results could contribute to the debate around the extent to which aphasic symptoms result from impaired cortical function, and to what extent from compensation for damaged processes through enhanced function of intact processes.

So far, the experiments presented in chapters five and six have only explored the influence of lexical and semantic factors on processing of phonetic contrasts within single words. There is considerable evidence in the literature that words are processed differently depending on whether they are heard in isolation or in a sentence context (see chapter one). Thus it is likely that complex interactions will exist not only between lexical and semantic factors within words, but also between these factors and aspects of the wider linguistic context. Further research with the participants in this study will explore the effects of sentence contexts on phoneme discrimination in words. Two experiments have been developed using a semantic judgment paradigm, in which participants are asked whether each sentence makes good sense. In one experiment the sentence context precedes the target word, while in the other experiment the sentence context occurs after the target. Sentences are either semantically plausible, or are implausible due to a single contrast being altered in one word to produce that word's minimal pair. (For instance, two test sentences are *'The girl buttoned her coat'* and *'The girl buttoned her goat'*.) The same word pairs are contrasted in these sentence judgment tasks as in the word discrimination and picture-word verification tasks reported here. This will allow for direct comparison of within-word and within-sentence factors on the processing of phonetic contrasts. The results of these sentence judgement tasks will also be considered in light of the findings of experiment one, in which sentence contexts were demonstrated to influence word recognition. Taken together, these five experiments will further advance understanding of the complex interactions between different representational levels in auditory processing.

An important implication of the findings of the two phoneme discrimination experiments that have been presented is the predicted effect of linguistic context on phoneme discrimination in non-test conditions. Controls showed no effects of word and picture contexts on their accuracy of phonological encoding, which was almost infallible in all three tests of discrimination. They also showed clear evidence of making lexical selections on the basis of the acoustic input rather than the semantic context. This suggests that normal listeners are unlikely to make errors in speech perception induced by the linguistic context, provided that listening conditions permit unambiguous acoustic signals to be received. This is in accordance with the findings of other authors that phonological encoding by normal listeners is only modulated by the linguistic context under poor listening conditions, or when acoustic information is ambiguous (e.g. Connine & Clifton 1987). In contrast, aphasic listeners may be influenced to a much greater degree by the linguistic context, particularly in the perception of phonetic contrasts that they have difficulty encoding. For the most part this should prove an effective (automatic) compensatory strategy, since the context will usually guide them to correctly identifying the intended target. However, there will be instances when the actual word spoken sounds similar to a word that appears more congruent with the context e.g. when an unusual event is described, or where a topic change has taken place in the conversation without detection by the aphasic listener. Under such circumstances, the aphasic listener may be induced by the context to misidentify the spoken target, resulting in a breakdown of communication. It may be helpful for aphasic people and their conversation partners to be alert to such a possibility, in order to recognise and repair such conversational breakdowns when they occur.

Three related experiments have now been presented, each of which has explored a different aspect of auditory processing in normal and aphasic listeners. Some implications of the findings of all three experiments for theoretical models of auditory processing will now be considered in chapter seven.

Chapter 7 Theoretical discussion and implications for clinical practice

Introduction

Three experiments exploring auditory discrimination and word recognition have been presented. These have revealed a number of complex interactions between representational levels in the processing of both normal and aphasic listeners. Phoneme discrimination is influenced both by featural aspects of the acoustic signal, and by the lexical and semantic context in which contrasts are perceived. Word recognition is influenced by factors including word frequency, neighbourhood density, imageability, and sentential context. These findings are summarised in Appendix 13. In this chapter some of the key findings are discussed in relation to three types of theoretical account of auditory processing. These include examples of cognitive neuropsychological, localist connectionist, and distributed connectionist approaches. These approaches, which were introduced in chapter one, differ both in terms of their underlying assumptions regarding representation and process in speech perception, and in terms of the degree to which processing mechanisms are made explicit. It is argued that the cognitive neuropsychological approach, whilst enormously important in refining our understanding of normal and disordered language processing, is currently limited by underspecification of the theoretical models. In contrast, connectionist models that have been implemented computationally provide explicit accounts of processing that can be more directly evaluated in the context of the experimental data. Two connectionist models are discussed. One of these, TRACE, fits the description of a localist connectionist model as introduced in chapter one, while the Distributed Cohort Model is a distributed connectionist model. While it is argued that neither model is able to fully account for the experimental findings, the model based on distributed representations provides the best fit with the data. Some remaining research questions are identified, and clinical implications are briefly considered.

Cognitive neuropsychological models

Cognitive neuropsychological models in the 'box-and-arrow' tradition are probably the most influential theoretical accounts in guiding current clinical intervention for aphasic single-word processing impairments in the United Kingdom. (See Kay & Terry 2004 for a review of studies that have used the PALPA assessment battery; see also Whitworth, Webster, & Howard 2004 (in press) for an extensive review of cognitive neuropsychological therapy studies). Among the best known of these are the related models of Ellis & Young (1988; 1996) and Kay, Lesser & Coltheart (1992) (see chapter one for a review). These models have been widely taught for nearly two decades during the pre-registration education of speech and language therapists, where they are commonly presented as the best theoretical basis for understanding aphasic impairments. The Kay, Lesser & Coltheart model explicitly underpins selection of assessment tools, and the interpretation of assessment findings, in clinical assessments such as the PALPA battery. Their description of auditory processing is certainly compatible with many published reports of clinical data, and has facilitated the development of therapeutic interventions carefully targeted at the specific level of processing impaired in individual aphasic patients. In particular, this model accounts neatly for the dissociations between word sound deafness, word form deafness and word meaning deafness described by Franklin (1989). It also has a number of advantages over more recent connectionist models of auditory processing. One of these is that the model explicitly includes all stages of processing, from auditory analysis through to semantic representations, whereas most connectionist models of auditory processing explicitly account for only some of these processes (some limitations of TRACE and of the Distributed Cohort Model are discussed below). A second advantage of the cognitive neuropsychological models is that auditory processing is integrated within a broad model of word processing that also accounts for many aspects of reading, writing, speaking, and repeating. Although many researchers would argue that the Kay, Lesser & Coltheart model has been superseded, it continues to inform clinical decision making in aphasia assessment and therapy more than any other model of single word processing. Indeed, the assumptions of this model continue to underpin research into therapies for aphasic auditory processing disorders (e.g. Francis, Riddoch, & Humphreys 2001; Maneta, Marshall, & Lindsay 2001; Morris, Franklin, Ellis, Turner, & Bailey 1996). For these reasons, the experimental data obtained in this study were considered within the framework of Kay, Lesser and Coltheart. However, where the model proved to be inconsistent with the data, the predictions of the two related models of Ellis & Young (1988; 1996) were also explored.

Certain clear predictions can be made on the basis of the proposed unidirectional flow of information within the Kay, Lesser and Coltheart model from auditory analysis, through the auditory input lexicon, and into the semantic system. One of these is that the semantic properties of words, such as imageability, should have no influence on the recognition of word forms. This is because access to a word's semantic representation can only take place once that word has been recognised within the lexicon. This model therefore predicts no influence of imageability on either reaction times or accuracy in auditory lexical decision. However, this prediction is not supported by the data in this study. With regard to reaction times, the control group responded significantly faster to high than to low imageability words (remembering that this pattern was only demonstrated for the low frequency set, due to a confounding of imageability with neighbourhood density within the high frequency set). One of the aphasic participants (AL) also responded faster to high imageability words, although this result fell just short of significance. Thus it appears that imageability, which is by definition a semantic property, exerts a facilitative effect on the speed at which words are recognised within the auditory input lexicon. A similar finding was reported by Tyler, Voice & Moss (1996). Patterns of response accuracy also point to an influence of imageability on auditory word recognition. Three of the aphasic participants (AL, JWh and TDS) made more errors on low imageability than high imageability words, although this result was not significant for any of them. However, for the aphasic group as a whole, responses were significantly more accurate for high imageability words (within the high frequency set). This is similar to the pattern reported for MK (Howard & Franklin 1988). Thus it seems that for controls and at least some aphasic listeners, words are more easily recognised when they are highly imageable. This finding cannot easily be explained within the Kay Lesser & Coltheart model, unless it is suggested that the lexical decision is actually made at a semantic level after the word meaning has been accessed (as is suggested by the authors). However, the fact that controls' reaction times were more heavily influenced by neighbourhood density than by imageability when these two factors were confounded seems to mitigate against this, suggesting as it does a strong influence of the phonological word-form at the decision stage.

The predictions of the two versions of the model proposed by Ellis & Young (1988; 1996) were therefore considered in relation to the effects of imageability. Both of these models incorporate a route by which information from the semantic system can flow to the auditory input lexicon. This route might therefore overcome the shortcoming of Kay Lesser & Coltheart in being unable to account for imageability effects on lexical decision. However, Ellis & Young's account lacks any discussion of the processing mechanisms involved in this feedback, preventing explicit predictions as to the precise effect of such feedback on word recognition. We might reasonably assume that the feedback mechanisms are facilitative and exert their influence during on-line processing of a word, with words that have stronger semantic activation receiving greater facilitation. However, in their discussion of this feedback route, Ellis & Young do not appear to attribute any role for the semantic representation of a word to influence recognition of that word. They justify the feedback connection because it explains how the semantic context in which a word is heard influences its activation (1996 p.144). This presumably reflects the wealth of evidence in the literature that semantic priming speeds word recognition, but there is no explicit discussion of whether the semantic properties of the word itself might influence recognition. Further, the authors (1996 p.472) explicitly state that a patient whose impairment lies in the links between the auditory input lexicon and the semantic system should be unimpaired in both speech sound perception and in auditory lexical decision. This clearly implies that access to semantic representations will not influence word recognition, and thus is incompatible with the presence of an imageability effect in auditory lexical decision.

The other key findings of the lexical decision experiment related to the effects of lexicality, word frequency, and neighbourhood density. However, none of the Kay, Lesser & Coltheart or Ellis and Young models makes any predictions regarding the effects of these experimental factors, since they specify neither the nature of the representations at each level, nor the processing mechanisms involved in mapping between different levels of representation. This is despite lexicality, frequency and neighbourhood density being well-established psycholinguistic variables known to affect performance on auditory lexical decision, and is discussed further below. Similarly, the Kay, Lesser & Coltheart model allows very few explicit predictions of performance on the tests of phoneme discrimination in experiments two and three. There is nothing in the model to predict whether the type or position of phonetic contrasts would influence speed or accuracy of processing. As the model makes no predictions about the effects of these main variables, neither can it predict the effects of interactions between these variables and the contextual factors under investigation.

One of the few explicit predictions that can be made is that the same patterns of performance according to type of phonetic contrast should be found, no matter whether contrasts occur within nonwords or words. This is because information can only flow from the auditory analysis system to the lexicon, providing no mechanism by which lexical information could influence phonological encoding. This prediction was not supported by the data. With regard to the reaction time data, the control group showed clear differences in the encoding of different types of phonetic contrast dependant on the context in which those contrasts were presented. For contrasts in initial position, the type of phonetic contrast affected processing speed in nonword discrimination but not word discrimination. For contrasts in final position, type of phonetic contrast affected reaction times in both nonword and word discrimination, but with some differences in the rank order of contrast types.

Among the aphasic participants, AL and JWh both showed differences in the effect of contrast type on reaction times between the nonword and word discrimination tasks. While this may argue against a model that treats discrimination of nonwords and words alike (since acoustic-phonetic analysis takes place prior to lexical access), a lack of effect on reaction times in one of the tasks might equally have been due to uncontrolled factors producing greater variability in one set of data. JW's reaction times, on the other hand, are more clearly incompatible with the model prediction since he showed differences in the rank order of reaction times for contrast types between the two tasks. Thus the control group and at least one of the aphasic participants showed an influence of lexicality on the speed of encoding the different phonetic contrasts. The aphasic participants (AL, JWh, TDS and TVR) also showed differences in accuracy of discriminating different types of contrast dependant on the lexical context. Since differences in either reaction time or accuracy for different types of contrast reveal patterns of phonological encoding, these differences between nonword and word discrimination results suggest that lexicality does influence encoding both in control and at least some aphasic listeners. This discrepancy is in accord with a number of published studies demonstrating effects of lexicality on phonetic perception (e.g. Caplan & Utman 1994), as discussed in chapter one. The prediction of Kay, Lesser & Coltheart that auditory analysis cannot be influenced by lexical representations is therefore undermined.

The predictions of Ellis & Young regarding effects of lexicality on phoneme discrimination may be different to those of Kay, Lesser & Coltheart. This is because one of their versions (1996 p.192) includes a bidirectional route between the auditory analysis system and the auditory input lexicon. This may allow feedback from lexical representations to influence auditory analysis, thus allowing the possibility of differences in discrimination between nonword and word tasks. However, since there is no explicit description of the nature of auditory analysis, nor of how lexical feedback might operate, no explicit predictions can be formulated regarding the type of differences that might exist between the two tasks.

A further explicit prediction that emerges from the Kay, Lesser & Coltheart model is that phonological encoding should be the same whether a word is heard in isolation or in the context of the picture of a phonological neighbour (as in the picture-word verification task). This prediction too arises from the unidirectionality of the route from acoustic analysis to the auditory input lexicon. Since there is no source of feedback to the acoustic analysis system, semantic representations cannot influence its operation either directly or indirectly. This assertion is not supported by the data. The control group's reaction times showed differences in the rank order of contrast types between word discrimination and picture-word verification. Four of the aphasic participants also showed differences in the effect of contrast type on reaction times between the two tasks. Although for three of them (AL, JW and JWh) this finding may be unreliable (as discussed in chapter six), the difference in effect for the fourth (TDS) as well as for the group is robust. With regard to accuracy of response, three aphasic participants (AL, TDS and TVR) made significantly more errors on picture-word verification than on word discrimination. Two of them showed a significant difference in the effect of contrast type on accuracy between the two tasks. Although for one (JWh) this is difficult to interpret since she was close to ceiling on both tasks, for the other (AL) this result is reliable. The aphasic group as a whole also showed a trend towards a difference in the effect of contrast type on accuracy dependant on whether or not a picture was simultaneously presented. Therefore, both control and aphasic reaction times, and aphasic accuracy, are inconsistent with the model's prediction that phonological encoding of words will be unaffected by picture contexts.

The Ellis & Young (1996) model may allow for different predictions about the effect of picture contexts on phonological encoding, since there is a bidirectional route between the auditory input lexicon and the semantic system. Although picture/object processing is not represented on either of Ellis & Young's models of auditory processing, a unidirectional connection from the object recognition units to the semantic system is included on a separate model of object processing (1996 p31). If this model is merged with their model of word processing, pictures might activate semantic representations of words during speech listening. It is possible that these semantic representations might in turn influence processing in the auditory input lexicon via the top-down connection from the semantic system. Lexical representations might in their turn influence auditory analysis by means of the top-down connection from the auditory input lexicon. It is therefore possible that the pattern of reaction times according to contrast type in words might be indirectly influenced by a picture context. However, since no specification of the representations or the processing mechanisms is given, no specific predictions can be made as to the origin of such an effect.

In summary, the models of both Kay, Lesser & Coltheart, and Ellis & Young (1988), fail to predict that imageability will influence lexical decision. The feedback route from semantics to the auditory input lexicon in Ellis & Young (1996) might in principle account for an imageability effect, but this appears to be ruled out in the authors' discussion of the route. Underspecification of all three models makes it unclear what effects word frequency and neighbourhood density would have on word recognition. Similarly, none of these models predict the effects of contrast type and syllable position that have been demonstrated on phonological encoding. Neither Kay, Lesser & Coltheart, nor Ellis & Young (1988), are able to account for the effects of lexicality and picture contexts on phoneme discrimination. The two feedback routes (from semantics to the lexicon, and from the lexicon to phonetic analysis) in Ellis & Young (1996) may provide an account of lexical and picture context effects on encoding, but underspecification prevents explicit predictions.

This summary clearly demonstrates the major shortcoming of the box-and-arrow type models. The lack of specification of both the nature of the representations and of the processing mechanisms makes it impossible to generate explicit hypotheses about many aspects of auditory processing, resulting in these models being virtually untestable in relation to these factors. This criticism is particularly true of Ellis & Young (1996), whose inclusion of bidirectional routes at each level, in the absence of a detailed account of processing, renders the model extremely powerful but unconstrained. It would be possible to account for a wide range of phenomena on this basis, and at the same time to construct very different accounts of the same phenomenon that were all compatible with the same model. Few patterns of performance are precluded, making it much harder to explicitly test the model itself. Of course, such criticisms of the cognitive neuropsychological models are not new[38] (e.g. Tyler 1992b pp.261-4). It must of course be borne in mind that these models were designed to describe the macro-structure and not the micro-structure of the language processing system, and so it is perhaps unreasonable to expect them to explain our findings in such detail. Finally, despite their limitations the insights that such models make available have profoundly influenced understanding of both normal and aphasic processing. Cognitive neuropsychology has provided a theoretical motivation for detailed clinical assessment and effective targeted therapy of single word auditory processing impairments in aphasia.

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[38] For a discussion of some theoretical and empirical issues related to the localist assumption underlying cognitive neuropsychological models, see Farah (1994).

TRACE – a localist connectionist model

As a widely known example of a fully implemented connectionist model, TRACE (McClelland & Elman 1986) addresses the main criticism of the cognitive neuropsychological models. This is because both the nature of the representations and the processing mechanisms are computationally explicit, allowing for explicit predictions to be tested against the experimental data. In addition, TRACE is of particular interest because of its highly interactive nature. Not only do features activate phonemes, and phonemes activate words, but feedback connections allow words to facilitate phonemes and phonemes to facilitate features. This allows for testing of hypotheses regarding the effects of lexicality not only on lexical activation, but also on prelexical encoding of the acoustic signal. The premise that acoustic-phonetic processing can be influenced by context remains contentious in the literature (as reviewed in Chapter One), and is of significance to the discussion of the locus of context effects shown in these experiments.

Considering performance on lexical decision, TRACE predicts faster responses to words than nonwords. This is because the model's processing ceases once there is only one word level unit remaining active (occurring at a time akin to the psychological 'recognition point'). When a word is processed, the most strongly activated word-level units laterally inhibit all other word-level competitors, thus speeding their return to resting activation levels. When a nonword is processed, any neighbouring word-level units will initially be activated. As the model cannot stabilize on any single word-level unit, iterative cycles of processing will continue attempting to fit the input until all word-level units have dropped out. The effects of lateral inhibition will also be weaker since no single word reaches peak activation, therefore it will take longer for competitors to drop back to resting activation levels. This prediction is supported by the finding that the control group, and one aphasic participant (TDS), responded faster to words than nonwords. It may be important that analyses of both control and aphasic group data revealed interactions between the effects of lexicality and the variation between individual participants, due to differences in the degree to which lexicality speeded decisions. It should be possible to simulate such individual variation within TRACE. Adjustment of weights on the connections from word to phoneme units would alter the facilitative effect of active word units, while altering the weights of the lateral connections between words would alter the inhibitory effect exerted by words on their competitors. It would be useful to implement such adjustments computationally to determine what effect these changes would have on other aspects of processing, and whether these reflected differences between participants across a range of tasks.

It is also more likely in TRACE that errors will be made on nonwords than on words. As the model attempts to find the best fit between the acoustic signal and stored word-level units, top-down facilitation and lateral inhibition adjust activation levels of the phoneme units. Activation increases in phonemes that are constituents of activated word units, and reduces in other phonemes. These modulated activation levels feed back up to the word level units, increasing activation levels in already highly active word units. This increases the probability of a word-level unit reaching its threshold, even if the input was in fact a nonword. However, such errors should only occur when the difference in activation levels of similar phoneme units is relatively small. This is because the degree of top-down facilitation and lateral inhibition is proportional to the strength of activation, since adjustment of weights occurs through a multiplication function. If the input is the nonword 'bip', for instance, and the /p/ unit is very much more highly activated than the /t/ unit, the effects of lexical facilitation on the /t/ unit are unlikely to be sufficient to result in false recognition of the word 'bit'. However, if phonological encoding of place of articulation is ambiguous such that the /p/ and /t/ phoneme units have similar levels of activation, then the facilitation provided by the 'bit' word-unit may be sufficient to result in classification of the ambiguous phoneme as /t/. Context will therefore have its greatest effect when the speech signal is most ambiguous, for instance due to impaired phonological encoding.

Such a pattern has been reported by Caplan & Utman (1994). Their patient showed an impairment in the perception of voicing contrasts, and made errors on nonwords in lexical decision when stimuli differed from a word only in the voicing of one segment. A group study by Boyczuk & Baum (1999) also found effects of lexical status on phonetic judgements by aphasic listeners that were strongest around the category boundary. The results of the aphasic group in the current study also appear to fit TRACE's prediction, since more errors were made on nonwords than words. However, individual analyses revealed a less straightforward picture. While three of the group (AL, TDS and TVR) made more errors on nonwords, a fourth (JWh) made more errors on words. Similar patterns were reported by Martin, Breedin & Damian (1999), who reported three patients, one of whom like JWh made more errors on words in lexical decision. The existence of such patients presents a challenge for TRACE's account of lexical competition. However, this challenge might be accommodated by the introduction of a computational 'lesion' to the model. If the impairment in word recognition arose partly from reduced activation of lexical representations (as proposed by Milberg, Blumstein, & Dworetsky 1988 to account for the reduced priming effects from distorted words in non-fluent aphasic participants), then this could presumably be modeled in TRACE. By reducing the weights of bottom-up connections from the phoneme to the word level, the probability would increase that individual word units would fail to reach sufficiently high activation levels to be recognised. This would produce an increase in rejection of words in the lexical decision task, as shown by JWh. Such a prediction would need to be implemented computationally to determine whether it did indeed produce the expected pattern of performance on this and other tasks.

The finding that controls respond faster to high than low frequency words is more problematic for TRACE. Although its authors acknowledge the likelihood that word frequency is important in speech perception, they chose not to represent this variable in the model. TRACE in its implemented form cannot therefore make any prediction or provide any explanation of the nature of frequency effects in word recognition. McLelland and Elman do suggest that frequency effects could in principle be accommodated, either through variation in the resting activation level of word units, or through variation in the strength of phoneme-to-word connections (p.60). Although they do not elaborate further on these possibilities, resultant changes to the model's behaviour can be inferred. For instance, if frequency were represented at the lexical level as in the first suggestion, high frequency words would start off with higher resting levels of activation. This would result both in their having a stronger inhibitory effect than low frequency words on their competitors, and in their needing less additional input activation to reach a level at which the system would stabilise. Fewer iterative cycles would therefore be required for the system to stabilise on a high frequency word than on a low frequency one, producing faster responses to high frequency words. Such adaptations would however need to be implemented computationally in order to determine their actual effects on performance.

The results of lexical decision revealed, in accordance with many reports in the literature, an important influence of neighbourhood density on word recognition. TRACE predicts that words with many neighbours will be recognised more slowly than words with few neighbours. This is because each word-level unit will suppress activation levels in its neighbours by means of the lateral inhibitory connections between them. The larger the active cohort, the more inhibition will be exerted on each member within the cohort, producing weaker activation levels for each individual word unit. The weaker the activation of each word unit, the longer it will take for the model to stabilise on a single word. This prediction is supported by the data, since the control group and two of the aphasic participants (JW and TDS) showed a positive correlation between neighbourhood size and reaction time.

One limitation of TRACE in comparison with the cognitive neuropsychological models discussed earlier is that it does not include a semantic level of representation, and makes no attempt to account for semantic processing. As with word frequency, the authors acknowledge the likelihood that higher level contextual influences are important in word recognition but chose not to elaborate the model to take account of this (pp. 60-61). TRACE therefore makes no predictions about nor provides explanation of the effects of imageability in lexical decision. However, Tyler, Voice & Moss (1996) proposed an extension to the model to include a level of localist semantic representations. They suggested that feedforward and feedback connections would exist between lexical and semantic levels. Just as lexical forms are activated by and feedback to phonemes, so semantic representations would be activated by and feedback to lexical forms. Although this extension to the model has not been implemented computationally, the implications are worth considering. If TRACE were extended as proposed, then it would be predicted that high imageability words would be recognised more quickly than low imageability words. This is because highly imageable words would produce stronger activation at visual/conceptual levels. These visual/conceptual representations could facilitate greater activation of semantically related word-level units by means of the top-down facilitatory connections to the lexical level. In turn, the more highly activated word units would exert a greater inhibitory effect on activation in their lower imageability competitors through lateral inhibitory connections. The model would therefore stabilize on a single word unit more quickly. This would be compatible with the finding that the control group, as well as one aphasic participant (AL) responded faster to high imageability words. The extended model would also predict that more errors would be made on low than high imageability words. This is because low imageability word units would both generate less activation at visual/conceptual levels, and would receive less top-down facilitation than high imageability word-units. With weaker activation at both word-form and visual/conceptual levels, the model would be more susceptible to noise and less certain of stabilizing on the correct word-unit. This is also compatible with the finding that, once the confounding effect of neighbourhood density was removed, the aphasic group made more errors on low imageability words.

As discussed above in relation to the results of lexical decision, TRACE predicts faster processing of words than nonwords in the phoneme discrimination tasks. Phonological encoding should be faster for words than for nonwords, because feedback from the lexical level raises activation of constituent phonemes, which in turn increases the suppression of non-constituent phonemes through the lateral connections between phoneme units. The system would therefore require fewer iterative cycles before stabilising when the input is a word than when it is a nonword. However, this prediction is not supported by the data. Mean reaction times for the control group were slightly faster overall to nonwords than to words. For initial contrasts this difference approached significance, while for final contrasts it was just significant (although in both instances there were individual differences between participants). Not only is this pattern different to that found on lexical decision, but it also differs from the lexical advantage across a range of tasks that is commonly reported in the literature. Since the same control group produced such apparently conflicting results across the two tasks, it is most likely that the difference in direction of the lexicality effect is related to differences in the task demands between phoneme discrimination and lexical decision. One clear difference is that in lexical decision participants know that any item might potentially be a word, and thus requires an attempt to match the input to a lexical representation in order to make a decision. In contrast, participants are aware in the nonword phoneme discrimination task that none of the items are words, and they do not need to access word-forms or meanings in order to respond. This could speed up the decision process, as participants would only need to attend to featural and/or phoneme levels. If this is the case, then there must be a degree of executive control over the apparently automatic processes involved in phonological encoding.

This would certainly be in keeping with the findings of Hugdahl et al. (2003) who demonstrated differences in symmetry of cortical activation, dependant on whether participants were instructed to listen to the nonwords or to the words in a set of stimuli comprising both. It has been suggested that aphasic listeners have impairments of attention and resource allocation that negatively affect their processing abilities in auditory lexical decision (Murray, Holland, & Beeson 1997), and also that aphasic listeners may be impaired in adjusting the focus of listening to spectral regions that carry the most important information (Divenyi & Robinson 1989). Such attentional modulation of speech perception is not represented in any way within TRACE (or any current connectionist models), and will not occur since the model always activates word level units in response to phonetic input. The effects of attention would need to be taken into account in a more complete model of speech perception.

A further prediction of TRACE is that, when phonemic representations are ambiguous, then fewer discrimination errors should occur on words than nonwords. The data are consistent with this prediction. For those individual aphasic participants that showed an overall effect of lexicality on accuracy of discrimination, the advantage was for words. The aphasic group as a whole also showed a significant lexical advantage in accuracy. The word advantage might operate in one of two ways, dependant on whether one or both of the ambiguously activated phonemes were consistent with a word. If only one of the phoneme contenders were congruent with a word, this would increase the possibility of that phoneme being perceived rather than a competitor that resulted in a nonword. So taking the example above, if the input activated /bɪ/ followed by both /p/ and /t/, facilitation from the word ‘bit’ would increase activation of the /t/ phoneme. (This would produce the same lexical effect as reported by Ganong (1980). Accuracy would be increased when the input was in fact a word, but decrease when the input was a nonword. Accuracy for words would not be improved in this way if phoneme level activation were ambiguous, and both phoneme candidates mapped onto word forms. An exception to this would occur if activation at the phoneme level favoured the correct target phoneme over its competitors, even marginally. This would produce more activation of the congruent word-form than its competitors (assuming neighbourhood density were equal). The lexical activation would feedback to the phoneme level, increasing activation in the target phoneme and decreasing activation in competitors. This should increase the possibility of the correct phoneme being perceived. Thus it is possible to explicitly account for the effect of lexicality on discrimination accuracy within TRACE.

More problematic is the effect of the picture context on accuracy of discrimination. The aphasic group as a whole made significantly more errors in picture-word verification than in word discrimination, with possible reasons for this discussed in Chapter 6. TRACE as implemented cannot account for this difference since it has no semantic level of representation. However, the Tyler et al (1996) proposed extension to include a semantic level within TRACE could in principle account for the increased error rate of the picture context. This is because semantic representations activated by the picture will raise levels of activation in related word forms, which would in turn raise activation in constituent phonemes. This would increase the probability of a phoneme being categorized as congruent with a highly activated word form.

Among the most interesting findings of the two phoneme discrimination experiments are the effects of the type of phonetic contrast on processing by both control and aphasic listeners. The featural level of processing within TRACE was examined to determine whether this model could predict the patterns found experimentally. The input to TRACE is encoded across a set of seven dimensions adapted from the acoustic-articulatory feature system of Jakobson, Fant & Halle (1952). These dimensions (power, vocalic, diffuse, acute, consonantal, voiced, and burst) were each encoded as a continuum of values from 1-8, rather than as the binary values proposed by Jakobson et al.. Phonemes are represented as mappings from a fixed set of values across the seven feature dimensions. The degree of similarity between two phonemes relates both to the number of features across which their values differ, and to the degree to which their values diverge within each feature. So, for instance, /p/ differs from /b/ on the two features 'voice' (which has the value 1 in /p/ and 7 in /b/), and 'burst' (which has the value 8 in /p/ and 7 in /b/). However, /p/ differs from /g/ across the four features, 'diffuse' (valued at 7 in /p/ and at 2 in /g/), 'acute' (valued at 2 in /p/ and at 3 in /g/), 'voice' (valued at 1 in /p/ and 7 in /g/), and 'burst' (valued at 8 in /p/ and 3 in /g/). Based on these featural differences, the authors were able to calculate the degree to which the featural specifications of any two phonemes correlated with each other (p.16). The sets of contrasts tested in the phoneme discrimination experiments were therefore analysed according to TRACE's featural system, to determine how easy TRACE should find each contrast to discriminate. The intention of this was to compare the average discriminability of contrasts (in terms of both the number of features that differed, and the degree to which values diverged on each feature) across the four contrast types (voice, place, manner, and two-feature contrasts). Unfortunately it was not possible to carry out this analysis for all the contrasts tested in the phoneme discrimination experiments. This is because the implementation of TRACE included only ten consonants, with many of the consonants contrasted in these experiments not represented within the model. Without the featural specifications, the discriminability of contrasts involving consonants not represented in TRACE could not be calculated. Of the experimental contrasts tested, discriminability could be calculated for 7/8 voice contrasts, 5/8 place contrasts, 2/8 manner contrasts, and all of the two-feature contrasts. This analysis revealed the following distribution of discriminability scores between the sets of items (Table 50):

Contrast type	Mean number of contrasting features	Mean correlation between phonemes
Voice	2	.77
Place	3	.56
Manner	5	.35
Two feature	5	< .31

Table 50. Discriminability of phonetic contrast sets according to featural specification of TRACE.

It should be noted that correlations below .20 (all of which occurred within the two-feature set of experimental contrasts) were not reported by McLelland and Elman. In these cases the value of .2 was used in the discriminability analysis here, although actual values may be much lower. The actual mean correlation for the two-feature set may thus be considerably lower than the value stated. The average discriminability within each set of contrasts must also be interpreted with caution, since not all contrasts were included in the analysis (particularly for the manner contrasts). However, the combination of the two measures of discriminability does permit cautious predictions as to expected patterns of performance. Two feature contrasts should certainly be easier for TRACE to discriminate than one feature contrasts, since they are distributed across more featural dimensions and have lower correlations. In addition, the analysis suggests that of the one-feature contrasts, voice contrasts should be the most difficult to discriminate, followed by place, then manner contrasts. These predictions are consistent with the distribution of controls' reaction times to the different contrast types in nonword discrimination. They are also consistent with the finding that the aphasic group made more errors on place and voice contrasts than manner and two-feature contrasts.

It was then considered whether TRACE could account for the differences in effect of contrast type found between the nonword and word discrimination tasks in experiment two. The facilitation from words to phonemes in this model leads to a number of behavioural predictions. One of these arises from the fact that the effect of lexicality accrues over time as an increasing proportion of the input is processed. The effect of feedback from word units to phonemes will therefore be stronger at the offset than the onset of words. Experimental support for this aspect of the model came from Marslen-Wilson & Tyler (1980), who showed that the lexical advantage for speed of phoneme monitoring increased for phonemes that occurred later in the word. It was also reported by Tyler (1992b) that one aphasic listener (JG) made most discrimination errors on word final place contrasts and was insensitive to word-final distortions that changed words into nonwords in other tasks, suggesting an increasing effect of lexical feedback for later-occurring segments. It follows from this that the influence of featural representations on speed and accuracy of processing should be greatest at the word onset, before top-down facilitation has built up; thus, the effect of contrast type on phoneme discrimination should be stronger in initial than final position in words.

This prediction receives some support from patterns of aphasic accuracy in nonword and word discrimination. Although group analyses revealed highly significant effects of contrast type in both initial and final positions across the two tasks, more subtle distinctions were revealed by the individual analyses. In nonword discrimination, four of the aphasic participants showed significant effects of contrast type in initial position, and three showed significant or almost significant effects in final position. In word discrimination however, only two individuals showed a significant effect of contrast type on accuracy in initial position, and only one even approached a significant effect in final position. This appears to be consistent with the prediction of TRACE that featural information will have less effect on processing of final contrasts in words. However, this interpretation remains uncertain, as the difference in effect may be partly due to the overall lower error rates on word discrimination rather than to a lesser influence of featural information per se. The prediction is not, however, supported by the control group's data, where in fact the converse is true. Although in nonword discrimination controls showed a highly significant effect of the type of phonetic contrast on reaction times in both initial and final positions, in word discrimination (and picture-word verification) the only significant effects of contrast type were found on word-final contrasts. Thus it appears that featural information played a greater role in controls' processing of word offsets than word onsets. The finding that the effects of lexicality can be seen in the processing of phonemes that occur early in words also accords with the findings of Cutler, Mehler, Norris & Segui (1987). They reported that for unambiguous phonemes, the lexical advantage for speed of response in phoneme monitoring can be seen even for phonemes in initial position. However, according to TRACE lexical effects take time to accrue (since there is no lexical activation until the lexical level has received the initial outputs of the phoneme level), and so should not play a significant role in processing of word onsets.

So despite the attractiveness of TRACE in capturing many aspects of human performance on speech perception, including an explicit account of the mechanisms by which lexical context might influence phonological encoding, the model is unable to account for a number of experimental findings. In particular, TRACE predicts that top-down feedback from word to phoneme levels will increase for phonemes that occur later in words. However, data presented in this study suggest a greater effect of top-down feedback on the processing of word-initial phonemes than of word-final phonemes. There are also a number of other experimental findings for which TRACE provides no explicit account. These include the effects of word frequency and imageability on word recognition, and the influence of semantic contexts and task-related attentional factors on phonological encoding. The findings of these experiments were therefore considered against the predictions of a third theoretical model that is distinct in a number of ways from both the cognitive neuropsychological and localist connectionist models discussed so far.

The Distributed Cohort Model – a distributed connectionist model

A very different account of lexical representation and processing within connectionist paradigms is provided by those models based on distributed representations. An example of such models that was described in chapter one is the Distributed Cohort Model of Gaskell & Marslen-Wilson (1997). The results of the lexical decision and phoneme discrimination experiments were therefore compared to the predictions of Gaskell & Marslen-Wilson to explore whether an assumption of distributed representations might overcome some of the limitations of TRACE in accounting for the data.

The predictions that the Distributed Cohort Model makes regarding the results of the lexical decision experiment proved to be largely similar to those discussed in relation to TRACE. However, the two models are quite different in the processing mechanisms from which these predictions arise and thus provide alternative accounts of normal and aphasic processing in spoken word recognition. One prediction of the Distributed Cohort Model is that words will be processed faster than nonwords, due to the nature of the lexical competition process. The point at which a word is 'recognised' by the model is the time when the network's distributed output pattern is sufficiently close to a single word representation, and sufficiently distant from all that word's competitors. This would normally coincide with the word's uniqueness point. This allows explicit criteria to be determined for both 'yes' and 'no' responses in the lexical decision task. The authors explicitly state that a 'yes' response would rely on the successful isolation of a single lexical item matching the speech input (p.629). This isolation is defined in terms of a level of separation between the relative distances of the word hypotheses from the blended output (p.630). Conversely, the 'no' response to a nonword input in the lexical decision task would be made when the output pattern was sufficiently distant from all word representations. Since the onsets of all the nonword stimuli in experiment one were also word onsets, the decision to reject these nonwords could only be taken once the blended output representation had moved sufficiently far from all of these word hypotheses. The presence of an active word hypothesis would thus delay the 'no' response marginally beyond that word's uniqueness point. This is because the active word representation would be exerting a draw on the output blend, although it would not draw the blend sufficiently close to generate a 'yes' response. This lexical influence would delay the movement of the blend through semantic space away from the word hypothesis required for generation of the 'no' response (p.629). The prediction that responses to words would be faster than responses to nonwords is supported by the data, since the control group and one of the aphasic participants (TDS) had faster reaction times to words.

The same characteristic of the model would also predict that, if errors occurred, responses would be more accurate to words than to nonwords. Again this prediction arises from the draw exerted by active word hypotheses on the blended output of the model. If, for instance, input to the model from the phonetic feature units were ambiguous, such that the model's phonological representation was equally compatible with a word and a nonword, then the active word representation would draw the blended output closer to itself. This would increase the likelihood of the model stabilising on that word rather than a neighbouring nonword. Aphasic impairments might presumably be simulated by lowering of the criterion separation level. This should result in increased false 'recognition' of nonwords, because the blended representation generated by a nonword input would more frequently result in a single word representation becoming sufficiently isolated, by chance, from its competitors to result in a 'yes' response. The dynamic time-course of processing cycles in the Distributed Cohort Model provides one possible account for the observation that JW sometimes rejected a nonword in auditory lexical decision, then moments later indicated that he had made a mistake and that the item had been a word (see chapter three)[39]. The effect of lexicality would be predicted to be greatest for nonwords that were structurally very similar to words, since such nonwords would be subject to the draw exerted by neighbouring words to a greater extent than

[39] Although it is recognised that participants may sometimes revise their decisions due to unwitting tester cues, it is considered unlikely that this occurred here. This is because the test was presented and responses recorded by computer without any intervention by the researcher, because the researcher was highly experienced in testing language processing in aphasic and other populations and so aware

nonwords that were less word-like. Although the degree of similarity between nonwords and words was not controlled in this experiment (save to ensure that the high and low imageability and frequency word sets were evenly matched), it has been demonstrated that nonwords that are made up of phoneme sequences that occur more often in words are responded to more slowly in auditory lexical decision than those made of less often occurring sequences (Vitevitch, Luce, Pisoni, & Auer 1999). A deficit simulated through a lowered critical separation level might be considered in terms of a positive response bias, and is also analogous to Milberg, Blumstein & Dworetsky's (1988) claim that Wernicke's aphasics have reduced thresholds for lexical selection. This fits well with the data of three of the aphasic participants (AL, TDS and TVR, although none of them would be described as Wernicke's aphasics) who made more errors on nonwords, as well as the pattern demonstrated by the aphasic group as a whole. (Indeed, the multiple attempts at each item in spoken picture naming demonstrated by TDS and TVR are compatible with there being too much competition between lexical candidates. However, the very different nature of the lexical decision and naming tasks, and the limited naming data, makes it difficult to relate the two sets of results with any certainty). A further consequence of such an impairment would be an increase in lexical and/or semantic errors in word recognition, since the chance of the blend being sufficiently close to a target word's competitor would be increased.

However, the prediction of a lexical advantage in the lexical decision task is not in accordance with the performance of JWh, who made more errors on words than nonwords. One way in which the model might be able to explain such a pattern would be if featural analysis were so distorted or diminished that few lexical hypotheses were activated by the input. In this case, the model might fail to generate a blended representation that was sufficiently close to any single word representation for recognition to occur. However, this account would not hold true for JWh, since her accuracy of phoneme discrimination in word pairs (shown by experiment two) was close to ceiling and within the range of the controls. It was suggested in chapter four that JWh's nonword advantage may reflect a bias to respond 'no' in the lexical

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of the need to avoid giving cues, and because the responses that JW changed his mind about had in fact been correct.

decision task, since she also demonstrated a lack of confidence in her responses on a number of other tasks. If this interpretation is correct, the Distributed Cohort Model should be able to account for a negative response bias such as this. This might be modeled through raising the criterion separation level required for making a 'yes' response. This should result in slower responses and a decreased probability of a single word representation becoming isolated from all its competitors, particularly for words in dense similarity neighbourhoods. Such a deficit might be understood in terms of a negative response bias, or could also be considered analogous to the notion that some aphasic listeners have raised thresholds for lexical selection (Milberg, Blumstein, & Dworetsky 1988). There is some evidence in JWh's background profile to support the notion of her having raised lexical thresholds since, at least in some tasks such as written picture naming, her lexical access appeared to be 'all or nothing'.

A further prediction of the Distributed Cohort Model is that high frequency words will be recognised more quickly than low frequency words, with the effect of frequency emerging naturally from the nature of the competition process. When the model activates representations for more than one word (that is, prior to the target word's uniqueness point), the distributed semantic representation of each word hypothesis is activated simultaneously. Since the semantic representations of phonological neighbours are usually unrelated to each other, there is little similarity between the competing semantic hypotheses. The model therefore produces a blend of all the hypotheses that are active. Where a specific node is indicated to be *on* in one hypothesis and *off* in a competing hypothesis, the model follows a set of rules to calculate the output value of that node, and it is these rules that give rise to effects of frequency. The mean value of each node for all the active hypotheses is calculated, with the value of the node in each hypothesis weighted by the number of times that representation was encountered during training. Frequency effects arise from two aspects of this competition process. First, the mean value of each node in the blend is adjusted towards the value of the more frequent word. That is, words that were presented more frequently during training have higher weightings, and so have a greater influence on the mean value for each node than words that were presented less frequently. The output blend representation will therefore be closer to the distribution of higher frequency words. The second aspect of the frequency effect results from the process by which the blended representation is modified over time to achieve a better fit with the active hypotheses. With each iterative cycle, the model tries to make the blend closer to the representations of all the remaining candidates. This process of error reduction is also biased towards the more frequent words. Each time that values are adjusted, the model moves the blend further towards the representations of frequent words than of less frequent words. It will thus take fewer iterative cycles for the model to stabilise on representations of high frequency words. Gaskell & Marslen-Wilson argue that this probabilistic frequency effect will occur even when the network is performing perfectly (p. 644-645). This prediction is consistent with the control group's faster responses to high frequency words. The Distributed Cohort Model can also provide an account of frequency effects on accuracy of auditory word recognition. Just as the nature of the competition process speeds processing for higher frequency words, it also increases the probability that the model will isolate the representation of a high frequency word. Since both frequency and imageability would exert their draw on the blend simultaneously, this could neatly account for the interaction between frequency and imageability often seen in aphasia, with more errors on words that are low in both frequency and imageability.

The Distributed Cohort Model predicts that words with small neighbourhoods will be recognised more quickly than words with large neighbourhoods. This is because all word representations are distributed over the same set of output nodes, resulting in interference between words when more than one candidate is active. As described above, the model produces a blended output from the frequency-weighted average values of each node, including in the calculation the value of that node within the representation of each candidate word. When there are many active candidates the resultant blend will be further on average from any single word representation than when the blend is produced from few word candidates. It will therefore require a greater number of iterative cycles to move the blend sufficiently close to a single word representation to produce a 'yes' response for words in dense phonological neighbourhoods than for words with few neighbours. This feature of the model is in accordance with the experimental finding from the control group, as well as three of the aphasic participants (JW, TDS and TVR), that reactions are faster to words with few neighbours.

The fact that the Distributed Cohort Model includes a semantic level of representation suggests that this model may account for some phenomena, such as imageability effects, that were beyond the scope of TRACE. The organisation of the semantic space as implemented, however, does not predict any effect of imageability on word recognition. The semantic representation of a word is represented by a random pattern of 0s and 1s distributed across a set of fifty binary output nodes. These patterns are arbitrarily related to the words' distributed phonological representations. The authors liken this to a micro-featural representation of word-meaning (p.618), in the sense that each semantic node relates to a semantic feature, although the nature of the semantic features is not specified. The value of 0 or 1 assigned to a semantic node in a word's semantic representation indicates the relevance of that feature to that word's meaning. However, the authors point out that their semantic representations differ from other micro-featural representations (such as Hinton & Shallice 1991) in terms of the 'sparseness' of the features. Whilst in Hinton & Shallice's model only a small proportion of features are assigned positive values within the representation of any individual word, within the Distributed Cohort Model all word meanings are represented by fifty percent of semantic nodes being set to 1. This level of semantic density was incorporated as a result of the mechanisms by which lexical hypotheses compete with each other. Gaskell (1996) demonstrated through statistical analyses that the more sparsely word meanings were represented across the semantic space, the fewer lexical hypotheses could usefully be activated in parallel. This arose because of the competitive 'blending' process; if each word were represented by only a small number of semantic nodes, then the likelihood increased that the blend that was produced during lexical competition would by chance fit well with the meaning of a word that was not in fact part of the competition process. The authors therefore chose to use dense semantic representations for all words, thus reducing the likelihood of the model accidentally isolating a semantic representation of an unrelated word.

Whilst this decision makes sense in terms of processing efficiency, it has a number of drawbacks. One is the psychological implausibility that any word would have a meaning consisting of half of all possible semantic features being set to 'on'. Although the authors clearly state that they have made no attempt to create a realistic representation of semantic knowledge (p.618), this nevertheless presents difficulties in the application of such a representational system to the interpretation of experimental data from human participants. A second drawback arising from their organisation of semantic space is that all words have equally 'rich' semantic representations; that is, all words are represented by twenty-five semantic nodes being on, and twenty-five semantic nodes being off. This does not allow for a semantic feature to be more relevant to one word meaning than to another. It would also preclude some types of semantic representation (such as meanings of highly imageable words) exerting a greater influence on the competitive blend than other types (such as abstract word meanings), since in processing terms all meanings are equal. This does not accord with the experimental findings that both control and aphasic groups showed significant effects of imageability on lexical decision performance.

It might of course be possible to adapt the Distributed Cohort Model to reflect semantic properties such as imageability, by altering the organisation of representations across semantic space. For instance, the proportion of semantic nodes that were set to 'on' in a word's representation could be proportional to that word's imageability rating, such that high imageability words would be represented by a higher proportion of semantic nodes than low imageability words. This would predict that high imageability words would thus exert a greater draw on the movement of the blended representation through semantic space. This should predict that high imageability words would be recognised more quickly and more accurately than low imageability words, as demonstrated in the data. However, the implications of such adaptations in computational terms are less easy to predict because, as already discussed, sparse representations by their nature present problems for the process of competitive blending. It might also be possible to model some effects of semantic category (such as the category-specific auditory processing disorders discussed in chapter one), by organising the semantic space such that words from the same category had similarly distributed semantic representations. Again, it would be necessary to implement such an adaptation computationally to determine how it would affect processing

Gaskell and Marslen-Wilson discuss the fact that neighbourhood density and semantic activation will interact with each other in the Distributed Cohort Model (p. 638). This is because a large number of word hypotheses being active simultaneously will result in low levels of semantic activation of each word, since the blend will be distant from each word. An implication of this is that, if the model were adapted to capture differences in imageability, low imageability words would be particularly susceptible to the reduced semantic activation resulting from the phonological neighbourhood. This would predict that phonological errors would occur more frequently on low imageability than high imageability words. This prediction might be tested using a word minimal pair discrimination task in which items were balanced not only for type of phonological contrast, but also for imageability.

Before moving on to discuss how well the Distributed Cohort Model accounts for the findings of the phoneme discrimination experiments, it is worth considering briefly another model that explicitly simulates effects of imageability on auditory processing and repetition. Martin & Saffran (1992) developed a connectionist model to account for experimental data from an aphasic patient who made semantic errors in spoken word repetition and was unable to repeat nonwords. The model was an adaptation of Dell & O'Seaghda's (1992) interactive activation model of word production, but was extended to include auditory input processing. In this model there are modular phonological, lexical and semantic networks linked by bidirectional connections between adjacent levels. Phonological representations are segmental, with each word comprising three segments equivalent to three phonemes. Only those phonemes required to represent the words in the simulation are included in the model. There are no phonetic features; this means that the model cannot simulate effects of contrast type on encoding and cannot be explicitly tested against the results of the phoneme discrimination experiments. At the lexical level there are only six words in the network, each represented by a localist node. These include the target word, *cat*, a semantically related word, *dog*, and two words that are phonologically related to each of the first two words: *hat, mat, fog* and *log*. Phonologically related words share two of their three phoneme nodes. The lexical nodes are connected to semantic representations that are distributed across a network of semantic feature nodes, with each word node linked to ten semantic feature nodes. Words that are semantically related overlap in the semantic feature nodes to which they are connected; the word nodes for *cat* and *dog* share one semantic feature. In this model, spreading activation is initiated by auditory input. Representations are first activated at the phoneme level, which feeds forward to nodes at the lexical level and from these to the semantic level. Activation also feeds back from the semantic level to the lexical level, and from the lexical level to the phoneme level. There are no thresholds – at any time point during processing the model will show the strength of activation across the network, with the most strongly activated lexical node being the most likely to be selected or output at that time.

The authors proposed that their patient's semantic errors in repetition could be accounted for by overly rapid decay of representations. Information from the phonological level would normally activate the target lexical form, as well as phonologically related competitors to some degree. These lexical representations in turn activate semantic representations, while feedback from the semantic level to the lexical level activates semantically related word-forms. At a given point in time, those lexical representations that were activated earlier (by input from the phonological level), would have decayed to a greater degree than lexical representations that were activated later (by feedback from the semantic level). So for the input word *cat*, the model will initially activate this word's constituent phonemes. These will feed forward to activate the target lexical node *cat*, as well as its neighbours *hat* and *mat* to some degree. Each of these lexical nodes will feed forward to activate the semantic features to which it is connected. In the case of the target lexical node *cat*, the representations of both *cat* and *dog* will be activated at the semantic level. These semantic features will feed back to the lexical nodes, such that the lexical nodes for *cat* and *dog* will receive input from *cat* and *dog* at the semantic level. In normal processing, the target word *cat* would be activated more strongly than other lexical nodes, since *cat* is the only node that would receive activation from both the phoneme level and the semantic level. Representations at each level decay, with the result that during the processing cycle the lexical activation from the phoneme units will decrease while the activation from the semantic units is still strong. The authors suggest that their patient's deficits arise from abnormally rapid decay rates. It is this factor that is proposed to give rise to semantic errors in repetition; the semantically activated word *dog* may be selected if the target lexical form of *cat* that was activated initially by phonemic input has decayed too far to be uniquely selected.

Thus this model provides an explicit account of interactions between lexical and semantic levels of representation, and so has the potential to account for effects of imageability on spoken word recognition. In a later study, Martin, Saffran & Dell (1996) explored effects of imageability on repetition by manipulating the semantic level of representation. It was assumed that when two lexical nodes share many semantic features they would tend to activate each other more strongly than if they share few semantic features. It was also assumed that high imageability words would share more semantic features than low imageability words. In the later simulation imageability was modelled by adjusting the number of semantic features that were shared between lexical nodes, such that the words *cat* and *dog* shared either one or three of their ten semantic features. The authors compared repetition accuracy on these simulations, and found that increasing the number of shared semantic features resulted both in fewer errors overall and in more semantic errors. They discussed this in terms of feedback to words with greater overlap at the semantic level (in their terms, highly imageable words) producing increased lexical activation, because related words would receive feedback from their own and each other's semantic representations. This would increase both the probability of an accurate response and the relative probability of a semantic error in repetition. It might be suggested that the same mechanism could account for the effect of imageability on auditory lexical decision that was demonstrated in chapter four. High imageability word nodes would activate each other to a greater degree via their shared semantic features than low imageability words. This increased feedback from semantic to lexical levels would increase lexical activation, and should result in faster and more accurate responses to high imageability words in lexical decision.

However, there are several limitations of this model, apart from the absence of prephonemic processing mentioned earlier. It was argued above in relation to the Distributed Cohort Model that dense semantic representations are psychologically implausible. The same argument applies here, as does the concern that the model might behave quite differently if the semantic space were scaled up to allow more sparse representations. The implication of representing each word's meaning through ten semantic features suggests that all words have equally rich semantic representations, which is counter-intuitive. It could also be problematic that imageability is equated with the degree of overlap in semantic features, since this appears to confound imageability with semantic relatedness. If the model were scaled up to handle a vocabulary of several thousand words, rather than the six words implemented, it would need to capture a range of semantic relations between words. It is unclear how the model would represent featural overlap differently between words that are closely related but not highly imageable e.g. *concept* and *idea*, and those that are highly imageable but more distantly related e.g. *fish* and *bird*. Nevertheless, this model is useful in providing an explicit account of how imageability may influence lexical representation during the time-course of auditory processing, and so addresses one limitation of the Distributed Cohort Model to which we shall now return.

Consideration of the effects of lexicality on performance in phoneme discrimination revealed that the Distributed Cohort Model accounts for, and is challenged by, the same aspects of the data as TRACE. The model clearly predicts that words will be processed faster than nonwords, as discussed above in relation to the lexical decision experiment. As with TRACE, this appears to be at odds with the finding that the control group discriminated nonwords faster than words, and indicates that a more complete account of auditory processing should include attentional modulation mechanisms. However, the facilitatory effect of word hypotheses on the movement of the blended representation through space is in accordance with the finding that the aphasic group were more accurate in discriminating words than nonwords. The Distributed Cohort Model, like TRACE, predicts that the effects of lexical facilitation should accrue over time as more of the input is processed, and the blended representation moves closer to the most highly active word hypotheses. The effects of featural differences in the acoustic signal should be greatest at the word onset, before the lexical effect has built up. Thus this model too is supported by aphasic accuracy results, but challenged by the finding that the control group showed a stronger effect of phonetic feature type in final than initial position in words.

The ability of the Distributed Cohort Model to account for the effect of the type of phonetic feature contrast on discrimination performance was then considered. It is important to note that this model takes as its input an abstract featural representation of the acoustic signal, rather than the acoustic signal itself. This means that acoustic-to-featural analysis is taken as given rather than explicitly modeled. The authors justify this in terms of the computational cost of simulating acoustic analysis, and the desire to train the network in a reasonable amount of time (Gaskell & Marslen-Wilson 1997 p.617). Although this model was not designed to address the mapping from acoustic to phonetic representations, this design has the effect of precluding any explicit predictions about the earlier stages of processing. It might be illuminating in future to combine the Distributed Cohort Model with a system that can take actual speech signals as input. This would raise the possibility of simulating impairments at the level of primary auditory processing as demonstrated in a number of studies of aphasia (e.g. Morris, Franklin, Ellis, Turner, & Bailey 1996), to explore the effect that such impairments would have on lexical access within this model.

In the Distributed Cohort Model, the acoustic signal is represented as the output of a set of eleven binary units corresponding to Jakobson, Fant and Halle's (1952) system of phonetic features. Perceptual information from these units is mapped simultaneously onto the representation of a word's form and meaning. It was considered possible that effects of contrast type, such as those shown in this study, might arise from the organisation of the feature units. If they were organised so that some types of contrast were represented by a higher number of feature nodes, then these contrasts would have a greater influence on activation of lexical and semantic nodes. For instance, if manner contrasts were distributed across more phonetic features than place contrasts, then manner contrasts would produce greater differences in input activation than place contrasts, and would require fewer processing cycles than place contrasts before the model stabilised. To test whether this might be the case, the set of contrasts making up the phoneme discrimination stimuli of experiment two were analysed according to Jakobson, Fant & Halle's (1952) featural system as implemented by Gaskell & Marslen-Wilson. Under their system, all phonetic contrasts are described using a finite set of binary features (consonantal, vocalic, diffuse, grave, flat, voice, continuant, strident, nasal, and compact), which describe aspects of both acoustic and articulatory correlates.

It did not prove possible to map the phonetic features of voice, place and manner onto the Jakobsonian features in any straightforward way. As described above in relation to the features in TRACE, this is because some of their features relate to more than one type of contrast, and some contrasts are discriminable across a number of their features. Therefore a detailed analysis was carried out to determine how each individual contrast within the phoneme discrimination experiments would be represented by the Jakobsonian features. For example, one of the place contrasts in the stimuli concerns /p/ and /t/. This contrast is represented by a difference only on the feature grave, and so is classed as a one feature contrast under Jakobson et al.'s system. However, another place contrast concerns /d/ and /g/. This contrast is represented by a difference on the two features, diffuse and grave, and was thus classified as a two-feature contrast under their theory. The number of features constituting these individual contrasts were then summed for each type of phonetic contrast in the stimuli, and compared across contrast types (Table 51).

Contrast type	Number of distinct Jakobsonian features				
	1	2	3	4	Total
Voice	k/g g/k k/g g/k p/b b/p d/t v/f				8
Place	p/t f/s m/n θ/s s/θ	d/g t/k k/t			11
Manner	b/m m/b d/n	p/f t/s s/t		l/n w/b	13
2 feature		p/d p/g	t/g r/s	ʃ/p ʃ/d k/s s/d	26

Table 51. Discriminability of phonetic contrast sets according to the featural specification of the Distributed Cohort Model

Under this system it emerges naturally that the set of two-feature phonetic contrasts (e.g. those contrasted by both place and voice) would be more easily discriminable than one-feature phonetic contrasts (those contrasted by only voice, place or manner) within the Distributed Cohort Model. This is because the phonetic two-feature representations would be spread across on average 3.25 Jakobsonian feature units, whereas phonetic one-feature contrasts would on average be spread across 1.33 Jakobsonian feature units. This prediction is consistent with both control and aphasic experimental data. It would also be possible to predict the rank order of difficulty in discriminating the one feature contrasts. The set of manner contrasts in the stimuli is spread across the most Jakobsonian feature units (mean 1.625 units), followed by the set of place contrasts (mean 1.375 units). Voice contrasts should be the most difficult to discriminate since they are each represented by only one Jakobsonian feature unit. This is precisely the pattern of reaction times shown by controls in discriminating initial contrasts in nonwords, and is also consistent with their pattern on final contrasts. Thus the predictions of the Distributed Cohort Model for speed of phonological encoding proved accurate.

There is also another means by which the Distributed Cohort Model might simulate effects of contrast type. This might result if the connections from the different features units to the distributed word forms (via the hidden units) were weighted differently for different feature types. For instance, if the output from the voice node were weighted more heavily than the output from the grave node, this would predict that a single Jakobson feature voice contrast such as /p//b/ would be easier to discriminate than a single Jakobson feature place contrast such as /p//t/. If, however, the connection weights from voice and grave nodes are set to the same level, then these two phonetic contrast types should be equally discriminable. Gaskell & Marslen-Wilson do not specify the connection weights for individual feature units, so it is not possible to determine whether these would have influenced patterns of encoding.

However, the data still present some difficulties for any model that uses a deterministic algorithm to simulate differences in the ease with which different contrast types are processed. A model that produces differences in speed or accuracy of processing the different contrast types on the basis of the number of Jakobsonian feature units representing those contrasts should always produce the same pattern. This does not at first sight accord with the finding that the rank order of discriminability for the different phonetic contrast types varies between individuals, as shown in aphasic accuracy data. It would be interesting to attempt to simulate aphasic patterns of accuracy on the Distributed Cohort Model. This might be achieved by modifying the connection weights from certain feature units, with the differences between individual aphasic listeners in terms of which contrasts were impaired arising from modification of different sets of featural connections. Whilst all of the aphasic participants in this study made errors on at least place and voice contrasts, reports in the literature have described patients who were impaired in discrimination of only one of these (e.g. Caplan & Utman 1994). Thus it might be hypothesized that the difficulty in discriminating voice contrasts exhibited by Caplan & Utman's patient might be simulated by reducing the weights of connections from the voice feature nodes to the distributed word representations in the Distributed Cohort Model. Alternatively, discrimination errors might be simulated by speeding decay rates and/or increasing the amount of random noise into the system. In this case, errors might result on any type of phonetic contrast, with those represented across fewer Jakobsonian feature units being more susceptible to noise related errors. This might produce a similar pattern to the discrimination difficulties of TVR, who made errors on all contrast types but with slightly more errors on place and voice contrasts than on manner and two feature contrasts. The results of such simulations on phoneme discrimination could then be compared to the actual patterns of results obtained from the aphasic participants in this study.

Another difficulty in the data for deterministic modeling of the effects of phonetic contrast type is that the rank order of phonetic contrast types varied between tasks both for control and some aphasic data. It would, for example, be necessary to account for those differences found between the nonword and word discrimination tasks in the rank order of controls' reaction times to the different types of contrast. The model would need to be able to simulate interactions between the outputs of the feature units and influences of lexical factors. However, at this stage the experimental data do not distinguish which aspects of lexicality were responsible for these effects. It would therefore be necessary to identify experimentally those factors that had contributed to the interaction, before constructing a detailed account of the interaction within the Distributed Cohort Model. For instance, it might be hypothesized that lexical factors such as frequency, neighbourhood density, and word length, and/or semantic factors such as imageability and concreteness, might be most important in this interaction. To test this hypothesis would require development of an experiment using word discrimination stimuli that were balanced for those lexical and semantic factors, as well as for contrast type and position. It would then be possible to identify specific interactions between the effects of contrast type and the effects of these lexical and semantic variables. Once those factors that were important were identified, the model would need to account for their influence.

Thus the nature of the lexical competition process embodied in the Distributed Cohort Model is able to account explicitly, and in a novel manner, for a number of aspects of both control and aphasic performance. These include the effects of lexicality, frequency and neighbourhood density on auditory lexical decision, as well as the effects of contrast type on phoneme discrimination. Like TRACE, the Distributed Cohort Model as implemented is unable to account for either the effects of imageability on word recognition, or for the time course of lexical effects on phoneme discrimination by controls. Nevertheless, this model has a number of distinct advantages over TRACE. These include the ability to account explicitly both for the effects of frequency on speed of processing, and for some aspects of semantic processing. In addition, Gaskell and Marslen-Wilson (2002 p.223) point out that effects of neighbourhood density emerge automatically from the process of competition between distributed representations, as opposed to TRACE where they result from the optional inclusion of lateral inhibitory connections between localised word units. Further, results of studies using functional neuro-imaging techniques (see Pulvermuller 2001) appear to strongly support the notion of distributed rather than localised linguistic representations in the human brain, lending greater psychological plausibility to distributed representational models. It is clear that we remain a long way from developing a detailed theoretical model that adequately accounts for all aspects of language representation and process. Current models, even within a discrete area such as auditory processing, are either underspecified or address only certain aspects of the language processing system. It will be necessary in future to refine and integrate such models to develop a hybrid 'super-model' that encompasses both low-level perception and higher level lexical, semantic and syntactic processing, eventually integrating these with much wider aspects of cognition and attention. The move towards such a super-model will be built on many small advances, and will no doubt require revision of some of the assumptions upon which existing models are based.

Final Comments

This thesis has presented a number of experimental investigations that were motivated primarily by the need to improve our understanding of auditory processing disorders in aphasia. Through greater understanding of such impairments, it may be possible to further refine and improve the effectiveness of interventions offered to people with aphasia. Although detailed discussion of therapy is beyond the scope of this thesis, a few final comments will consider some clinical implications of this research. One important finding is that aphasic listeners may have a greater reliance on semantic context than normal listeners to support their impaired auditory processing. In many circumstances, strategic compensation such as this may result in a phoneme discrimination impairment having less impact on functional comprehension than would be suggested by formal assessment. However, it may also indicate the need for conversational partners to be trained to recognise the subtle signs of comprehension errors in the aphasic person, and to employ strategies to avoid and repair such breakdowns. These might include strategies that enhance the semantic context, such as alerting the aphasic person before topic changes and by writing down key words. Such strategies have been shown to be effective by Maneta, Marshall & Lindsay (2001), who hypothesised that they had a beneficial effect not only on functional communication, but also on their patient's bottom-up auditory processing.

In clinical settings, the assessment of phoneme discrimination is typically carried out through administration of a single minimal pair test, with only overall accuracy considered to establish the presence or absence of impairment. The results of the experiments reported here clearly demonstrate the need to consider the complex interactions between representational levels in assessing aphasic auditory processing. It is suggested that assessment of phoneme discrimination should identify which types of phonetic contrast an individual is able to discriminate, their ability to discriminate contrasts in different positions within the syllable/word, and their ability to discriminate contrasts in different lexical and semantic contexts. The assessment process should aim to identify not only levels of impairment within the system architecture, but also more subtle aspects of dynamic processing (such as decay rates and thresholds for lexical access), since these may have a pervasive effect on functional performance. Of course it is important to be realistic in terms of the restricted resources and time available for detailed assessment in most clinical practice settings. The availability of computerised assessment tools could make detailed assessment more realistic, for instance through automatic analysis and reporting of results. There may also be further potential for development of computerised therapy programmes that would directly target those aspects of processing identified as impaired. Clinicians' time might thus be saved in terms of both assessment interpretation and treatment planning, with the further benefit of some therapies being supplemented by intensive computer-aided practice.

Despite auditory processing disorders being a common feature of aphasia, and one that can have a significant impact on both functional communication and quality of life, such impairments have received relatively little attention in the development of therapeutic interventions. There are few published accounts of auditory therapies, and not all studies have shown beneficial effects of treatment. In a recent systematic review carried out by the author of this study for the Royal College of Speech and Language Therapists (Taylor-Goh (Ed) 2004), only three robust single-case studies of therapy for word-sound deafness were identified. Of these, one study showed no improvement in phoneme discrimination (Maneta, Marshall, & Lindsay 2001), while the other two demonstrated specific beneficial effects of therapy on phoneme discrimination (Grayson, Hilton, & Franklin 1997; Morris, Franklin, Ellis, Turner, & Bailey 1996). Only Grayson et al.'s patient showed significant improvements in auditory comprehension. However, it is difficult to ascertain how far the improvement in comprehension was attributable to changes in phoneme discrimination, since auditory therapy was combined with semantic therapy. Thus the evidence base for treatment of auditory processing disorders is currently very limited. Further research is necessary to determine which approaches achieve the best functional outcomes for individual patients. For instance, it may be useful directly to compare treatment of phoneme discrimination aimed at improving bottom-up auditory processing with treatment of semantic processing aimed at maximising top-down facilitation. Factors influencing individual responses to these therapies, such as the severity of the discrimination impairment and/or access to intact semantic representations, would need to be determined in order for clinical interventions to be appropriately targeted. In future research it would also be useful to consider the effects of cues such as lip-reading information (e.g. Best & Howard 1994; Buchman et al. 1986; Maneta, Marshall, & Lindsay 2001; Shindo, Kaga, & Tanaka 1991), and how these interact with the phonetic and linguistic factors that have been explored in this study.

The development of cognitive neuropsychological models based on modular architectures represented a huge leap forward in our understanding of normal and aphasic language processing. These models allowed a move away from broad classifications of aphasia type, such as the prevalent Boston classification system (Goodglass & Kaplan 1983), towards a much more detailed understanding of individual patterns of impairment. This in turn initiated the development of clinical assessments and therapeutic interventions that directly target the impaired processing of aphasic individuals, many of which have been robustly demonstrated to have specific beneficial effects. Connectionist models have the potential to build on the advances in assessment and therapy achieved through application of neuropsychological models. Connectionist models might in future underpin assessments and therapies that are able to account for more of the fine detail of representation and processing, for instance by directly targeting dynamic processes such as decay rates. They may also be able to account for specific effects of therapy in terms of identifiable changes to language representations and/or processes, and contribute to an improved evidence base for aphasia therapy. Improved understanding of why specific therapeutic approaches are not equally effective for all individuals with apparently similar patterns of deficit could result in improved treatment outcomes. Future research in this area is necessary in order for people with aphasia to reap the rewards of these new insights.

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Appendix 1: Advertisement for control participants

CONFIDENTIAL

UNIVERSITY COLLEGE LONDON
Department of Phonetics and Linguistics
Wolfson House
4 Stephenson Way
London NW1 2HE

HELP NEEDED !!!

Earn £5.00 per hour !!!

We are looking for volunteers for research into speech and language processing.

If you are a native English speaker and have normal hearing, you can help us by carrying out some simple tasks. We are looking for adults of any age. You don't need any special skills or qualifications to take part.

What does the study involve ?

If you want to take part, we will ask you to do some language tests. These will be things like looking at pictures while listening to words and sentences. We will also test your hearing. There will be quite a lot of tests which will take about ten hours spread over a few weeks. We will arrange times to suit you. The tests might make you feel tired, but you will not be harmed in any way by doing them. The tests will be carried out at the Department of Phonetics and Linguistics, University College London. We will pay you £ 5.00 per hour for your time.

If you agree to take part, your name and personal details will be kept confidential. To find out more without any obligation please telephone or e-mail me, or write to me at the address above.

Contact:

Appendix 2: Information sheet for control participants

Wolfson House
4 Stephenson Way
London NW1 2HE

Project Information Sheet for Volunteers

Auditory and Linguistic Factors in Spoken Word Recognition in Aphasia

You are invited to take part in this research project. This sheet tells you about the project. You may also ask us any questions about the project. You do not have to take part in this study if you do not want to. If you decide to take part you may withdraw at any time without having to give a reason.

This study is about language processing in aphasia. Aphasia is a language problem which is often caused by a stroke. Aphasia can affect speaking, understanding speech, reading and writing. We want to find out about the kinds of language problems aphasia causes. We especially want to know how aphasia affects people when they are listening to speech. This will help Speech & Language Therapists find new ways to help people with aphasia.

We need healthy volunteers to help us with the study. We need them to do some language processing tests to find out how people who do not have aphasia carry them out. This will help us to understand the problems which people with aphasia have.

What does the study involve ?

If you want to take part, we will ask you to do some language tests. These will be things like looking at pictures and listening to words and sentences. We will also test your hearing. There will be a lot of tests which will take about ten hours spread over a few weeks. The tests might make you feel tired, but you will not be harmed in any way by doing the tests. The tests will be carried out at the Department of Phonetics and Linguistics, University College London. We will pay £ 5.00 per hour for your time.

If you agree to take part, your name and personal details will be kept confidential.

This research is being carried out by :

Celia Woolf
Professor Stuart Rosen
Maria Black

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Appendix 3: Consent form

UNIVERSITY COLLEGE LONDON
Department of Phonetics and Linguistics
Wolfson House
4 Stephenson Way
London NW1 2HE

Auditory and Linguistic Factors in Spoken Word Recognition in Aphasia[40]

	YES	NO
Have you received the information sheet about this study ?	☐	☐
Have you had a chance to ask more about this study ?	☐	☐
Have your questions been answered satisfactorily ?	☐	☐
Have you received enough information about this study ?	☐	☐
Do you understand that you may withdraw from this study		
- at any time	☐	☐
- without giving a reason ?	☐	☐

Do you agree to take part in this study ?

Which researcher has spoken to you about this study ?
Celia Woolf / Professor Rosen / Maria Black

Signed (subject) : Print name:

Signed (researcher) : Print name:
date :

All proposals for research using human subjects are reviewed by an ethics committee before they can proceed. This proposal was reviewed by the joint UCL/UCLH Committees on the Ethics of Human Research.

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Appendix 4: Advertisement for aphasic participants

HELP NEEDED !!!

We are looking for subjects for research into auditory processing in aphasia

"But he understands everything I say ..."

We are carrying out an investigation into the role of linguistic context in auditory word recognition in aphasia. We want to understand why some aphasic people who have impairments of auditory processing seem able to compensate for these difficulties when given a clear linguistic context, while others do not. This information will help us to develop clinical assessments of auditory word processing which take account of the effects of linguistic context, as well as to develop new therapies for the treatment of auditory processing impairments in aphasia. This research is being carried out by Celia Woolf, Professor Stuart Rosen and Maria Black of University College London.

If you know someone who may be willing to help with this project, please contact me for an informal discussion. We need subjects who have been aphasic for at least six months, and have impairments of phoneme discrimination and/or lexical access from auditory input. They must also live within reasonable travelling distance of London.

Contact: Celia Woolf MRCSLT

UCL

University College London
Phonetics and Linguistics Department
Wolfson House
4 Stephenson Way
London NW1 2HE

Appendix 5: Protocol

Research Project - Information for referring clinicians

'Auditory and Linguistic Factors in Spoken Word Recognition in Aphasia'

Ms Celia Woolf, Professor Stuart Rosen and Ms Maria Black
Department of Phonetics and Linguistics
University College London

Summary

This project will investigate auditory language processing in subjects with aphasia, an acquired language impairment resulting from neurological damage which affects both the expression and reception of language in spoken and written modalities, with the pattern and severity of impairments varying widely between individuals. It will comprise a series of detailed single case studies which will investigate patterns of auditory processing impairment in relation to the language processing systems of individual aphasic subjects.

The project will improve our understanding of the processes which enable some aphasic people to compensate for impaired auditory processing, thus contributing to the theoretical debate about the relationship between the processing of words and sentences. It will also lead to the development of clinical assessments relating to auditory processing which more accurately reflect some aspects of functional processing than is possible with current psycholinguistic assessments, resulting in more objective evaluation of the effects of therapy on functional comprehension. Improved understanding of auditory processing in context should enable clinicians to develop new therapies for aphasic clients to utilise contextual processing in order to compensate for impaired auditory word recognition, thus reducing the negative impact of auditory comprehension impairments on psychosocial well-being and functional independence.

The specific focus of investigation will be the ability of subjects to use the linguistic context (such as sentences) to compensate for difficulties in discriminating and recognising individual spoken words. This will be carried out by means of a battery of neuropsychological language assessments, some of which are published clinical assessments and others which have been specially devised for this study. (Normative data on those measures specially devised for the study will be obtained from normal age-matched controls). Measures of accuracy will be taken for all experimental tests and in addition reaction times will be measured for a subset of the test battery. These will be analysed in relation to cognitive neuropsychological models of language processing. Patterns of performance on the entire test battery will be analysed for each subject to develop a detailed profile of the individuals' language processing systems and patterns of aphasic impairment. Comparisons will also be made between subjects in order to identify any consistent performance factors which correlate with the ability to utilise linguistic context to compensate for auditory processing impairments.

The study will take place at the Department of Phonetics and Linguistics, University College London. The project will last from September 1999 till September 2001. Ethical approval for this study has been granted by the Joint University College London / University College London Hospitals Committees on the Ethics of Human Research (Study no. 99/0236).

Participation in Study

Approximately ten patients and ten healthy volunteers will be recruited to the study according to the following selection and exclusion criteria:

Subjects

Selection Criteria:

- Minimum age eighteen years.
- Native, (preferably) monolingual English speakers.
- Aetiology of stroke, minimum six months post onset.
- Confirmed diagnosis of acquired aphasia from referring clinician.
- Impairment of auditory processing evidenced by poor performance on phonemic minimal pair judgement and/or auditory lexical decision.
- Able to travel independently to University College London or willing to be visited at home for purpose of experimental assessment.

Exclusion criteria:

- Hearing thresholds above 40dB HL on pure tone audiometry at 1-4 kHz.
- Evidence of significant non-linguistic cognitive impairment.
- Presence of major mental or physical health problems likely to affect participation in the study.
- Inability to give informed consent using consent procedures tailored to individual communication needs.

Controls

Selection criteria

- Minimum age eighteen years.
- Native monolingual English speakers.
- Able to give informed consent using standard consent procedures.
- Able to travel independently to University College London or willing to be visited at home for purpose of experimental assessment.
- Control sample to reflect age range and educational background of subject sample.

Exclusion criteria

- Hearing thresholds above 40dB HL on pure tone audiometry at 1-4 kHz.
- Current or previous history of speech or language impairment (e.g. developmental speech/language impairment, specific learning disability, dyslexia).

- Presence of major mental or physical health problems likely to affect participation in the study.

Method

All assessment procedures used are non-invasive tests of auditory, visual and language processing. Subjects will be asked to respond in a prescribed manner (pointing, gesture, speech, writing or pressing a button) to sets of stimuli presented auditorily or visually. Stimulus presentation in some subtests will be live, and in others will be via headphones and/or computer screen.

An initial screening session will determine whether potential subjects meet the inclusion criteria for participation. If included in the study each subject will participate in two further stages of testing. The second stage will take approximately eight 1- 1½ hour sessions over a four week period, in order to obtain a detailed profile of the subject's language processing skills and impairments in input and output modalities. The third stage will also take approximately eight 1- 1½ hour sessions over a four week period, and will provide a detailed analysis of the subject's auditory language processing skills. In particular testing will reveal whether higher level representations influence the formation of or access to the prelexical and lexical codes. Results of these assessments will be interpreted in relation to the subject's individual language profile as well as to current theories of lexical processing.

Testing will be carried out on an individual basis either at University College London or at the subject's home if this is more convenient. Subjects will be reimbursed for traveling expenses and also paid £5.00 per session for participation.

Stage One : Screening

The first stage of assessment will take one session (1-2 hours). The purpose is to provide the subject with information relevant to the decision to participate in the project, and to confirm whether the subject meets the acceptance criteria related to presence of auditory language processing impairment and absence of significant hearing impairment .
Assessments carried out will be:
a) Nonword minimal pair judgment.
b) Auditory lexical decision (words matched for imageability and frequency).
c) Pure tone audiometry at 1-4 kHz.

Stage Two : Language Profiling

The second stage of assessment will take approximately eight sessions over a four week period. The purpose is to obtain a detailed profile of the subject's language processing skills and impairments in input and output modalities.
Assessments to be carried out:

Auditory Input Processing
a) PALPA Spoken Word to Picture Matching
b) PALPA Auditory Synonym Judgment
c) Test for Reception of Grammar (TROG) (Auditory presentation)
d) Sentence Semantic Anomaly Judgment

Orthographic Input Processing
e) PALPA Letter discrimination
f) PALPA Upper to Lower Case Matching
g) PALPA Written Lexical Decision
h) PALPA Written Word to Picture Matching
i) PALPA Written Synonym Judgment
j) TROG (Written presentation)

Spoken Output Processing
k) PALPA Spoken Picture Naming
l) PALPA Picture Rhyme Judgment
m) PALPA Written Word Homophone Judgment
n) PALPA Written Nonword Homophone Judgment
o) PALPA Word Reading Aloud
p) PALPA Nonword Reading Aloud
q) Spoken Narrative Description

Orthographic Output Processing
r) PALPA Written Picture Naming
s) PALPA Writing to Dictation Regular and Irregular Words
t) PALPA Writing to Dictation Nonwords
u) Written Narrative Description

Other Tests
v) Pyramids and Palmtrees (three picture version)
w) Birmingham Object Recognition Battery (Easy Object Decision)
x) Test of inference from visual scenes
y) Taped Conversation Sample

Following stage two there will be a break of approximately two weeks to allow preliminary analysis of test results prior to commencement of stage three testing.

Stage Three : Experimental Measures

This stage of assessment will take approximately eight sessions over a four week period. The purpose is to carry out a detailed examination of the subject's auditory language processing skills. In particular testing will reveal whether higher level representations have any influence on the formation of or access to the prelexical and lexical codes. Results of these assessments will be interpreted in relation to the subject's individual language profile as well as to current theories of lexical processing.

a) Auditory Minimal Pair Judgment
This test examines subjects' ability to perceive fine distinctions between phonemes. The subject will hear pairs of test stimuli, and will be asked to indicate whether they sound the same or different. The test will be carried out under two conditions: word and non-word.
b) Picture-word Verification
This test examines a subject's ability to perceive phonemic distinctions under a condition in which they are necessarily accessing post-lexical and semantic representations. In this task subjects will hear single words from the stimulus set used in test a) . They will be asked to judge whether the word matches a picture. Distractor words will be minimal pairs with target words.
c) Phoneme Discrimination by Semantic Anomaly Judgment
This test examines subjects' ability to perceive phonemic distinctions where target words are embedded in a semantically rich sentence context. Subjects will hear some sentences, and are asked to indicate whether or not each sentence makes normal sense. Each sentence frame is presented twice, once with an appropriate target word from the stimulus set embedded in it, and once with a word which is the minimal pair of the appropriate target but which is semantically anomalous in the sentence context.
d) Auditory Lexical Decision
This test examines subjects' ability to recognise words. Subjects hear one item at a time and are asked to judge whether it is a word. Half of the items are words and half are plausible nonwords. The set of words is balanced for word frequency and imageability.
e) Auditory Lexical Decision - stimuli blocked in semantically related groups
This test examines the effects of a simple semantic context on access to stored lexical representations. Subjects hear the stimuli one at a time and are asked to indicate for each stimulus whether they recognise it as a word.
f) Auditory Lexical Decision - stimuli presented in sentences
This test examines the effects of a semantically predictive sentence context on lexical access. Subjects hear sentences and are asked to indicate whether the sentence ends with a real English word. Each sentence frame is presented twice, once ending with a semantically appropriate word from the stimulus set and once ending with the corresponding phonologically derived nonword.
g) Target monitoring tasks
These tasks examine processing speed in accessing prelexical and lexical representations under several context conditions. They provide evidence of both the relative time course of access to different levels of representation, and the relative effects of the different kinds of context on speed of access to representations. The subject is instructed to respond by pressing a button immediately they hear a specified target within a stimulus set. Reaction times from onset of the target are measured. The test is presented under eleven conditions to compare access to different representational levels under various context conditions. The target stimuli relate to prelexical representations (phonemic targets), to lexical representations (rhyming targets), or to semantic representations (category targets). The different contexts comprise a randomised list of word or nonword stimuli presented in isolation, a semantically ordered list of word stimuli, or a list of semantically plausible sentences in which target word stimuli are embedded.

Appendix 6: Information sheet for aphasic participants

UNIVERSITY COLLEGE LONDON
Wolfson House
4 Stephenson Way
London NW1 2HE

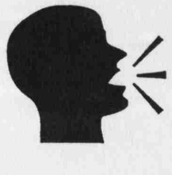
Information Sheet for Subjects

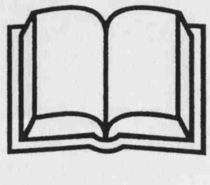
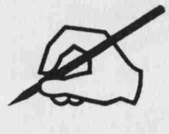
'Auditory and Linguistic Factors in Spoken Word Recognition in Aphasia'

You are invited to take part in this research project. This leaflet tells you about the project. You may also ask us any questions about the project. You do not have to take part in this study if you do not want to. If you decide to take part you may withdraw at any time without having to give a reason.

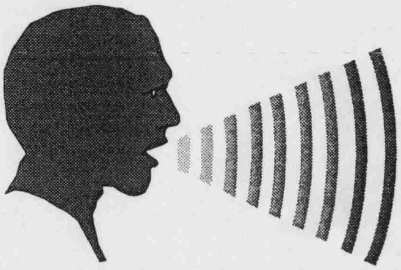
This study is about aphasia. Aphasia is a language problem. It is often caused by a stroke.

Aphasia can affect speaking, understanding speech, reading and writing.



We want to find out about the kinds of language problems aphasia causes. We especially want to know how aphasia affects people when they are listening to speech.

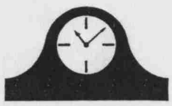


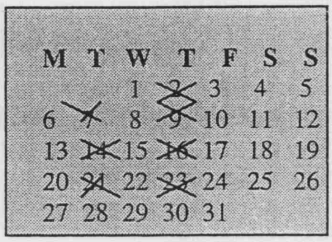
This will help Speech & Language Therapists find new ways to help people with aphasia.

What does the study involve ?

If you want to take part, we will ask you to do some speech and language tests. These will be things like looking at pictures and listening to words. We will also test your hearing.

There will be a lot of tests. It will take about 16 appointments.

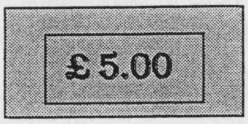


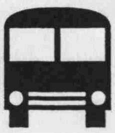


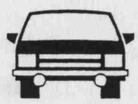
The tests might make you feel tired. You will not be harmed in any way by doing the tests.

We can do the tests at the University or at your home.

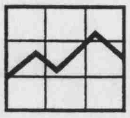
We will pay you £5.00 for each appointment. If you come to the University we will also pay your travel expenses.



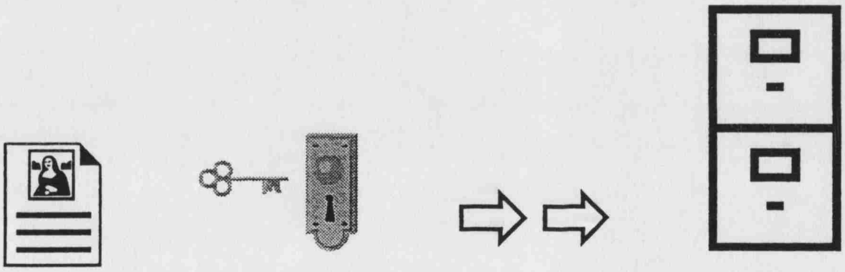




By doing the tests we may help you to understand more about your language problems. We do <u>not</u> expect the tests to make your language problems any worse or better.



If you agree to take part, your name and personal details will be kept confidential.



This research is being carried out by:

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University College London
Department of Phonetics & Linguistics

All proposals for research using human subjects are reviewed by an ethics committee before they can proceed. This proposal was reviewed by the joint UCL/UCLH Committees on the Ethics of Human Research.

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Appendix 7: Control group audiometry results

Name	Right ear			Left ear		
	1kHz	2kHz	4kHz	1kHz	2kHz	4kHz
AT	5	5	10	5	10	5
DB	10	10	5	15	15	10
DT	5	-5	10	5	-5	10
GH	15	15	40	20	10	35
JH	5	10	5	0	5	20
JS	10	0	5	0	0	5
MC	10	5	5	5	5	0
RM	5	10	-10	15	10	10
SF	10	15	0	0	15	10
WB	5	0	0	5	0	5

Control participants' hearing levels (dB) at 1000 Hz, 2000 Hz and 4000 Hz measured with pure tone audiometry.

Appendix 8: Sentence Semantic Anomaly Judgement items

Item	Anomaly Type
The children played with some toys.	none
The dog chased after the stick.	none
This restaurant serves really good food.	none
The table walked out of the kitchen.	verb requires animate agent, agent is non-animate
Fishermen often catch fish in the trees.	pragmatic/world knowledge
The family went out for a walk.	none
The ship sailed across the mountain.	verb semantic attribute (movement across surface of water) incompatible with lexical semantic attribute of mountain (solid)
We saw an elephant at the zoo.	none
That garden is full of flowers.	none
Most bookshops sell fruit and vegetables.	pragmatic/world knowledge
We watched a film on the radio.	lexical semantic attributes of theme and instrument incompatible (+/- visual)
The shopkeeper counted the money	none
This house is built of cotton.	pragmatic/world knowledge
My favourite vegetable is cheese.	lexical semantic relationships i.e. vegetable is not a superordinate of cheese
The baby drove the car.	pragmatic/world knowledge
The glass was full of orange juice.	none

Appendix 9: Auditory Lexical Decision Items (with pronunciation)

High Imageability High Frequency Items

audience	ˈɔːdɪəns	andience	ˈændɪəns
battle	ˈbætəl	biffle → birrel	ˈbɪɹəl
church	tʃɜːtʃ	slurch	slɜːtʃ
coffee	ˈkɒfi	cottee	ˈkɒti
fire	ˈfaɪə	fide → fider	ˈfaɪdə
hand	hænd	hend	hend
hospital	ˈhɒspɪtəl	hopsitle	ˈhɒpsɪtəl
hotel	ˈhəʊtel	hetal → heetel	ˈhiːtel
letter	ˈletə	lutter	ˈlʌtə
marriage	ˈmæɹɪdʒ	mirtage → mattage	ˈmætɪdʒ
mother	ˈmʌðə	mirter	ˈmɜːtə
night	naɪt	nirth → nime	naɪm
picture	ˈpɪktʃə	pisture → pisker	ˈpɪskə
plane	pleɪn	pline	plaɪn
radio	ˈɹeɪdɪəʊ	ragio → ramio	ˈɹeɪmɪəʊ
school	skʊəl	sprool → smule	smjʊəl
student	ˈstjuːdənt	stadent	ˈsteɪdənt
Summer	ˈsʌmə	sammer	ˈsæmə
village	ˈvɪlɪdʒ	vallige	ˈvælɪdʒ
window	ˈwɪndəʊ	wembow → wimbow	ˈwɪmbəʊ

Low Imageability High Frequency Items

attitude	ˈætɪtjuːd	antitude	ˈæntɪtjuːd
character	ˈkæɹɪktə	baranter	ˈbæɹəntə
concept	ˈkɒnsept	boncept	ˈbɒnsept
crisis	ˈkɹaɪsɪs	crasis	ˈkɹeɪsɪs
effort	ˈefət	affort	ˈæfət
fact	fækt	fict	fɪkt
idea	aɪˈdɪə	idia	iˈdɪə
length	leŋθ	clenth	klenθ
manner	ˈmænə	minner	ˈmɪnə
member	ˈmembə	mimber	ˈmɪmbə
moment	ˈməʊmənt	loment	ˈləʊmənt
opinion	əˈpɪnjən	opunion	əˈpʌnjən
principle	ˈpɹɪnsɪpəl	prisciple → pranciple	ˈpɹænsɪpəl
purpose	ˈpɜːpəs	purpise → parpose	ˈpɑːpəs
quality	ˈkwɒləti	shality	ˈʃɒləti
session	ˈseʃən	settion → setton	ˈsetən
system	ˈsɪstəm	drister	ˈdɹɪstə
theory	ˈθɪəɹi	pheory → veery	ˈvɪəɹi
thing	θɪŋ	sping	spɪŋ
thought	θɔːt	prought	pɹɔːt

High Imageability Low Frequency Items

alcohol	ˈælkəhɒl	halocle → alcoshol	ˈælkəʃɒl
axe	æks	afe	æf
cart	kɑːt	calt	kɑːlt
drum	dɹʌm	drim	dɹɪm
elbow	ˈelbəʊ	eltow	ˈeltəʊ
elephant	ˈelɪfənt	epilent	ˈepɪlənt
feather	ˈfeðə	foaster	ˈfəʊstə
funnel	ˈfʌnəl	fannel	ˈfænəl
gravy	ˈgɹeɪvi	gramy	ˈgɹeɪmi
monkey	ˈmʌŋki	dunkey	dʌŋki
onion	ˈʌnjən	otion → unshen	ˈʌnʃən
pig	pɪg	pib	pɪb
pill	pɪl	pell	pel
potato	pəˈteɪtəʊ	pitaro	peˈtɑːɹəʊ
pupil	ˈpjuːpəl	pupit	ˈpjuːpət
slope	sləʊp	slape	sleɪp
spider	ˈspaɪdə	spuder	ˈspjuːdə
tobacco	təˈbækəʊ	tanacco	təˈnækəʊ
tractor	ˈtɹæktə	tranter	ˈtræntə
wheat	wiːt	weast	wiːst

Low Imageability Low Frequency Items

analogy	əˈnælədʒi	atalogy	əˈtælədʒi
bonus	ˈbəʊnəs	binus	ˈbaɪnəs
clue	kluː	clee	kliː
deed	diːd	dend	dend
dogma	ˈdɒgmə	sogmy → sogma	ˈsɒgmə
episode	ˈepɪsəʊd	apisade	ˈæpɪseɪd
folly	ˈfɒli	felly	ˈfeli
gravity	ˈgɹævəti	grivity	ˈgɹɪvəti
irony	ˈaɪɹəni	itony	ˈaɪtəni
mercy	ˈmɜːsi	merly	ˈmɜːli
miracle	ˈmɪɹəkəl	minacle	ˈmɪnəkəl
pact	pækt	puct	pʌkt
plea	pliː	plen	plen
realm	ɹelm	reash → resh	ɹeʃ
satire	ˈsætaɪə	sutire	ˈsutaɪə
treason	ˈtɹizən	trenson	ˈtɹensən
tribute	ˈtɹɪbjuːt	trabite	ˈtɹæbaɪt
valour	ˈvælə	dalour	ˈdælə
woe	wəʊː	voe	vəʊː
wrath	ɹɒθ	prath	pɹɒθ

Appendix 10: Sentence frames for sentence lexical decision

High Imageability / High Frequency

Sentence Frame	Word	Nonword
The concert attracted a large	audience	andience
The soldiers went into	battle	birrel
Our wedding was held in	church	slurch
The mug was full of	coffee	cottee
The logs burned on the	fire	fider
The glove fitted her	hand	hend
The ambulance drove to the	hospital	hopsitle
Tourists often stay at a	hotel	heetel
The postman delivered a	letter	lutter
She accepted his hand in	marriage	mattage
The boy missed his father and	mother	mirter
Stars come out at	night	nime
The artist painted a	picture	pisker
The pilot flew the	plane	pline
Music was broadcast on the	radio	ramio
The teachers work at the	school	smule
The college enrolled another	student	stadent
After Spring comes	Summer	sammer
A town is bigger than a	village	vallige
The man looked out of the	window	wimbow

Low Imageability / High Frequency

Sentence Frame	Word	Nonword
That grumpy teenager has a negative	attitude	antitude
Romeo is a Shakespearean	Character	baranter
The students finally grasped the difficult	concept	boncept
The man was suffering a mid-life	crisis	crasis
The school report said he could make more of an	effort	affort
We must separate fiction from	fact	fict
He thought up another bright	idea	idia
The swimmer swam one	length	clenth
In Church you should dress in an appropriate	manner	minner
The social club admitted a new	member	mimber
The feeling only lasted a brief	moment	loment
The expert gave his	opinion	opunion
Fairness was his basic	principle	pranciple
The naughty child had done it on	purpose	parpose
Cheap furniture is of poor	quality	shality
The physio arranged another	session	setton
Stars and planets are part of the solar	system	drister
Einstein came up with a new	theory	veery
Having a treat is not such a bad	thing	sping
He dived in without giving it a second	thought	prought

High Imageability / Low frequency

Sentence Frame	Word	Nonword
Wine and beer both contain	alcohol	alcoshol
The woodcutter swung his	axe	afe
The horse pulled the	cart	calt
They danced to the beat of the	drum	drim
The boy grazed his knee and his	elbow	eltow
A trunk is the nose of an	elephant	epilent
The bird's tail had lost a	feather	foaster
The steamship had a large	funnel	fannel
On the roast beef she poured some	gravy	gramy
An animal that swings in the trees is a	monkey	dunkey
My favourite crisps are cheese and	onion	unshen
In the sty lives a big, fat	pig	pib
The doctor told him to swallow the	pill	pell
He ate sausages and mashed	potato	pitaro
The teacher praised the clever	pupil	pupit
The skier raced down the	slope	slape
A tarantula is a great big	spider	spuder
Cigarettes are made with	tobacco	tanacco
The farmer drives a	tractor	tranter
Farmers grow cereals like corn and	wheat	weast

Low Imageability / Low Frequency

Sentence Frame	Word	Nonword
She told the story by way of	analogy	atalogy
The workers earned a Christmas	bonus	binus
The detective found a vital	clue	clee
He was kind in word and	deed	dend
Political ideas are sometimes called	dogma	sogma
Watch the Eastenders wedding in next week's	episode	apisade
Their decision to keep going was pure	folly	felly
Astronauts float because there is no	gravity	grivity
Her jokes were full of sarcasm and	irony	itony
The prisoner pleaded for	mercy	merly
The old man's recovery was nothing short of a	miracle	minacle
The unhappy lovers made a suicide	pact	puct
The condemned man made a final	plea	plen
The king surveyed his	realm	resh
The comedy was a political	satire	sutire
The prisoner was charged with high	treason	trenson
The mourners laid flowers as a	tribute	trabite
The soldier received a medal for	valour	dalour
A sad person is full of	woe	voe
Sinners might incur God's	wrath	prath

Appendix 11: Phoneme Discrimination Nonword Stimuli

Note: Nonwords have been derived from word pair stimuli by changing the non-contrastive consonant in each word pair to produce non word items (except for bat/bag - wʌt-wʌg). This ensures that items from the two tests are closely matched thus allowing valid comparisons between word and non-word performance.

24 Different Nonword pairs varied by one distinctive feature:

One phoneme varied by voicing

dæk dæg	kəuf gəuf	pəuɹ bəuɹ	wʌg wʌk
paɪd paɪt	hæp hæb	gəuɹ kəuɹ	væs fæs

One phoneme varied by place

sig fig	lɔk lɔt	muf nuf	wʌp wʌt
gʌd gʌg	dæk dæt	tauθ taus	nɒs nɒθ

One phoneme varied by manner

dɛg nɛg	bæb mæb	teɪð seið	paɪt paɪs
laɪp naɪp	sɪm sɪb	fɔp pɔp	wɪs bɪs

8 Different Nonword pairs varied by two distinctive features

ʃɛm dɛm	ɹəuf səuf	kɪf sɪf	wʌt wʌg
θɪg θɪp	zəup zəud	ʃɑl pɑl	ðɒg ðɒt

Appendix 12: Phoneme Discrimination Word Stimuli :

24 Different Word pairs varied by one distinctive feature:

One phoneme varied by voicing

back bag	coat goat	pole bowl	mug muck
ride write	cap cab	goal coal	van fan

One phoneme varied by place

seed feed	pork port	moose noose	cup cut
bud bug	back bat	mouse mouth	moss moth

One phoneme varied by manner

deck neck	bat mat	tail sail	write rice
light night	rim rib	fork pork	win bin

8 Different Word pairs varied by two distinctive features

shed dead	rope soap	kick sick	bat bag
pig pip	rope road	shark park	dog dot

Appendix 13: Summary of experimental findings

Results Summary: Experiment 1 Lexical Decision

Participant: Control Group

	Simple Lexical Decision	Sentence Lexical Decision
Lexicality	Faster responses to words than nonwords. Controls vary in degree to which lexicality speeds responses.	No effect of lexicality on RTs. Lack of effect not due to greater variability in RTs.
Frequency	Faster responses to high than low frequency words.	No significant effect of frequency, although 8/10 controls had faster mean RTs to high frequency words.
Density	Faster responses to words with smaller neighbourhoods.	Faster responses to words with smaller neighbourhoods. Correlation only shown for high frequency word set, and fell just short of significance.
Imageability	Faster responses to high than low imageability words. Only shown for low frequency items since imageability confounded with density in high frequency items.	No effect of imageability on RTs for low frequency words. Apparent overall reverse imageability effect presumed due to confounding of imageability and density in stimuli, therefore ignore this.

Results Summary: Experiment 1 Lexical Decision

Participant: AL

	Simple Lexical Decision	Sentence Lexical Decision
Lexicality	More accurate to words than nonwords. No effect of lexicality on RTs (although faster mean RT to words).	More accurate to words than nonwords. Stronger lexicality effect than in simple LD. No effect of lexicality on RTs.
Frequency	No effect of frequency on accuracy, although slightly more errors on high than low frequency words. No effect of frequency on RTs.	More errors on high than low frequency words i.e. reverse frequency effect, but short of significance.
Density	No effect of neighbourhood density on RTs.	No effect of neighbourhood density on RTs.
Imageability	No effect of imageability on accuracy, although more errors on low imageability words. Faster responses to high imageability words (just short of significance).	No effect of imageability on accuracy, although more errors on low imageability words. No effect of imageability on RTs.

Results Summary: Experiment 1 Lexical Decision

Participant: JW

	Simple Lexical Decision	Sentence Lexical Decision
Lexicality	No effect of lexicality on accuracy. No effect of lexicality on RTs, although faster mean RT to words than nonwords.	More accurate to words than nonwords (result short of significance due to missing data). No effect of lexicality on RTs.
Frequency	No effect of frequency on accuracy or RTs.	No effect of frequency on accuracy, although more errors on low frequency words. No effect of frequency on RTs.
Density	Faster responses to words with lower densities.	No effect of neighbourhood density on RTs.
Imageability	No effect of imageability on accuracy. No effect of imageability on RTs.	No effect of imageability on accuracy, although more errors on low imageability words. No effect of imageability on RTs.

Results Summary: Experiment 1 Lexical Decision

Participant: JWh

	Simple Lexical Decision	Sentence Lexical Decision
Lexicality	More accurate to nonwords than words. No effect of lexicality on RTs.	More accurate to words than nonwords (just short of significance). Different direction of effect from simple LD. No effect of lexicality on RTs.
Frequency	No effect of frequency on accuracy, although more errors on low frequency words. No effect of frequency on RTs, although faster mean RT to high frequency words.	No effect of frequency on accuracy (at ceiling). No effect of frequency on RTs.
Density	No effect of density on RTs.	No effect of neighbourhood density on RTs.
Imageability	No effect of imageability on accuracy, although more errors on low imageability words. No effect of imageability on RTs, although faster mean RT to high imageability words.	No effect of imageability on accuracy (at ceiling). No effect of imageability on RTs.

Results Summary: Experiment 1 Lexical Decision

Participant: TDS

	Simple Lexical Decision	Sentence Lexical Decision
Lexicality	More accurate to words than nonwords. Faster RTs to words than nonwords.	More accurate to words than nonwords. Significantly greater lexical advantage than in simple LD. Faster RTs to words than nonwords.
Frequency	No effect of frequency on accuracy. No effect of frequency on RTs.	No effect of frequency on accuracy (at ceiling). No effect of frequency on RTs, although faster mean RT to high frequency words.
Density	Faster RTs to words with fewer neighbours.	No effect of neighbourhood density on RTs.
Imageability	No overall effect of imageability on accuracy, although more errors on low imageability words. No effect of imageability on RTs.	No effect of imageability on accuracy (at ceiling). No effect of imageability on RTs, although faster mean RT to low imageability words.

Results Summary: Experiment 1 Lexical Decision

Participant: TVR

	Simple Lexical Decision	Sentence Lexical Decision
Lexicality	More accurate to words than nonwords (result just short of significance). No effect of lexicality on RTs.	More accurate to words than nonwords. Faster responses to nonwords than words.
Frequency	No effect of frequency on accuracy (close to ceiling). No effect of frequency on RTs.	No effect of frequency on accuracy although more errors on low frequency words (close to ceiling). Faster RTs to high frequency words.
Density	Faster responses to words with fewer neighbours (shown for low frequency set only).	No effect of neighbourhood density on RTs.
Imageability	No effect of imageability on accuracy (close to ceiling). No effect of imageability on RTs.	No effect of imageability on accuracy although more errors on low imageability words (close to ceiling). No effect of imageability on RTs.

Results summary: Experiments 2 & 3 Phoneme Discrimination

Participant: Control Group

	Nonwords	**Words**	**Pictures**
Match	Faster responses to initially different than same pairs. Faster responses to same pairs than finally different pairs.	Faster responses to initially different than to same pairs. Faster responses to same pairs than to finally different pairs.	Combined initial and final contrast sets: faster responses to matching than non-matching items.
Position	Faster responses to initial than final contrasts.	Faster responses to initial than final contrasts.	No effect of position. Significantly different from word result.
Contrast type	Initial contrasts: fastest responses to 2-feature, then manner, then place, then voice contrasts. Three overlapping subsets by contrast type. Final contrasts: faster responses to manner and 2-feature than to voice and place contrasts. Two distinct subsets.	Initial contrasts: No effect of contrast type. Significantly different from nonword result. Final contrasts: Faster responses to 2-feature, then voice, then manner, then place contrasts. Two overlapping subsets.	Initial contrasts: No effect of contrast type. Final contrasts. Faster responses to manner and 2-feature contrasts than to place and voice contrasts. Two distinct subsets.

Results summary: Experiments 2 & 3 Phoneme Discrimination

Participant: AL

	Nonwords	Words	Pictures
Match	More errors on different pairs. No difference in reaction times to initially different and same pairs. Faster responses to same pairs than to finally different pairs.	No effect of match on accuracy, although slightly more errors on different pairs. Significantly different from nonword result. No difference in reaction times to initially different and same pairs. No difference in reaction times to finally different and same pairs. Trend towards difference from nonword result.	Trend towards more errors on non-matching items. No difference in speed of response to initially non-matching and matching items. Faster responses to matching than to finally non-matching items.
Position	No effect of position on accuracy. Faster responses to initial than final contrasts.	No effect of position on accuracy. No effect of position on reaction times.	No effect of position on accuracy. Not significantly different to word results, although seemed to make more errors on final contrasts in pictures than in words. Faster reactions to initial than final contrasts. Difference from words result just short of significance.

Contrast type	Initial and final contrasts combined: significant effect of contrast type on accuracy. Most errors on voice and place contrasts. Very low accuracy on place. Initial contrasts: significant effect of contrast type on accuracy. All errors on voice and place contrasts. Very low accuracy on both. No effect of contrast type on reaction times, although voice appears slower. Final contrasts: significant effect of contrast type on accuracy. Almost all errors on place contrasts, none on voice. Very low accuracy on place. Significant effect of contrast type on reaction times. No subsets found, although voice and manner appear slower than place and 2-feature.	Initial and final contrasts combined: No effect of contrast type on accuracy. Initial contrasts: trend towards effect of contrast type on accuracy. Most errors on voice contrasts. No effect of contrast type on reaction times to initial contrasts, although place appears slower. Final contrasts: No effect of contrast type on accuracy, although only made errors on voice and place. More errors on place than voice. No effect of contrast type on reaction times to final contrasts.	Initial and final contrasts combined: significant difference in effect of contrast type on accuracy from words results. Initial contrasts: trend towards/significant effect of contrast type on accuracy dependant on anlaysis. Slower responses to place than to 2-feature and manner contrasts when seed/feed included, but need for caution in interpreting. Final contrasts: significant effect of contrast type on accuracy, with most errors on place contrasts. No effect of contrast type on reaction times.

Results summary: Experiments 2 & 3 Phoneme Discrimination

Participant: JW

	Nonwords	Words	Pictures
Match	More errors on different than same pairs. Faster responses to initially different than to same pairs. Faster responses to same pairs than to finally different pairs.	More errors on different than same pairs. No difference in reaction times to initially different and same pairs. Significantly different from nonword results. Faster responses to same pairs than to finally different pairs. Significantly different from nonword results.	More errors on non-matching than matching items, with effect just short of significance. Faster responses to matching than non-matching items.
Position	No effect of position on accuracy. No effect of position on reaction times.	Trend towards effect of position on accuracy, with more errors on initial than final contrasts. Trend towards faster responses to initial than final contrasts.	No effect of position on accuracy. Significantly different from words results. No effect of position on reaction times.
Contrast type	Combined initial and final contrasts: significant effect of contrast type on accuracy. Very low scores on place and voice.	Combined initial and final contrasts: Significant effect of contrast type on accuracy, with most errors on voice and place.	Combined initial and final contrasts: no difference in effect of contrast type on accuracy between words and pictures results.

	Initial contrasts: significant effect of contrast type on accuracy. No correct responses to voice, and many errors on place contrasts. Some errors on manner. Significant effect of contrast type on reaction times. 2-feature faster than manner (slowest). Final contrasts: significant effect of contrast type on accuracy. Many errors on voice and place, with especially low score on place. No effect on reaction times, although voice appeared slower.	Initial contrasts: significant effect of contrast type on accuracy. No correct responses to place, and very low score on voice contrasts. Faster responses to 2-feature and manner contrasts than to voice contrasts. Trend towards difference in effect from nonword results. Final contrasts: trend towards effect of contrast type on accuracy. Some errors on voice, but most errors on place contrasts. No effect of contrast type on reaction times.	Initial contrasts: Significant effect of contrast type on accuracy. No correct responses to place contrasts, and few errors on voice contrasts. Trend towards effect of contrast type on reaction times when seed/feed excluded, with place contrasts appearing much faster. Need for caution in interpretation. Final contrasts: significant effect of contrast type on accuracy. Most errors on place contrasts, but also some errors on voice and manner contrasts. No effect of contrast type on reaction times.

Results summary: Experiments 2 & 3 Phoneme Discrimination

Participant: JWh

	Nonwords	Words	Pictures
Match	Combined initial and final contrasts: significantly more errors on different pairs. Faster responses to initially different pairs than to same pairs. Faster responses to same pairs than to finally different pairs.	Combined initial and final contrasts: No effect of contrast type on accuracy (close to ceiling). Significantly different from nonword results. No difference in reaction times to initially different pairs and same pairs. Trend towards difference from nonword results. Faster responses to same pairs than to finally different pairs. Significantly different from nonword results, due to greater degree of effect in words.	Combined initial and final contrasts: Trend towards more errors on non-matching items. No effect of match on reaction times.
Position	Trend towards effect of position on accuracy, with more errors on initial contrasts. Faster responses to initial than final contrasts.	No effect of position on accuracy (close to ceiling). Faster responses to initial than final contrasts.	No effect of position on accuracy (close to ceiling). No effect of position on reaction times. Trend towards difference from words results.

Contrast type	Combined initial and final contrasts: significant effect of contrast type on accuracy, with errors only on voice (mainly) and place contrasts. Initial contrasts: significant effect of contrast type, with errors only on voice and place. Very low score on voice. Significant effect of contrast type on reaction times. Faster responses to 2-feature and manner contrasts than to place and voice contrasts. Final contrasts: No effect of contrast type on accuracy. Close to ceiling. Only errors on place contrasts. No effect of contrast type on reaction times.	Combined initial and final contrasts: no effect of contrast type on accuracy, although only errors on voice and place contrasts (close to ceiling). Significantly different from nonword results. Initial contrasts: No effect of contrast type on accuracy, although only errors on voice contrasts (close to ceiling). No effect of contrast type on reaction times. Final contrasts: No effect of contrast type on accuracy, although only errors on place contrasts (close to ceiling). No effect of contrast type on reaction times.	Combined initial and final contrasts: significant difference in effect of contrast type on accuracy between words and pictures results. Initial contrasts: Trend towards effect of contrast type on accuracy when seed/feed included (close to ceiling). Only errors on seed/feed place contrasts, therefore difficult to interpret. Significant effect of contrast type on reaction times when seed/feed items included. Responses slower to place contrasts than all others. Same pattern when seed/feed excluded, but not significant. Interpret with caution. Significantly different from words results, but again interpret with caution. Final contrasts: No effect of contrast type on accuracy (close to ceiling). Trend towards difference from words results. No effect of contrast type on reaction times.

Results summary: Experiments 2 & 3 Phoneme Discrimination

Participant: TDS

	Nonwords	Words	Pictures
Match	Initial and final contrasts combined: no effect of match on accuracy. Faster responses to initially different than to same pairs. No difference in reaction times to same pairs and to finally different pairs.	Initial and final contrasts combined: more errors on different than same pairs. Trend towards difference from nonword results. Trend towards faster responses to same pairs than to initially different pairs. Significant difference from nonword results. Faster responses to same pairs than to finally different pairs. Significant difference from nonword results.	Initial and final contrasts combined: No effect of match on accuracy (close to ceiling). No effect of match on reaction times.
Position	No effect of position on accuracy. Faster responses to initial than final contrasts.	No effect of position on accuracy. No effect of position on reaction times.	No effect of position on accuracy (at ceiling on initial contrasts, close to ceiling on final contrasts). No effect of position on reaction times.

Contrast type	Initial and final contrasts combined: significant effect of contrast type on accuracy. Only made errors on place and voice contrasts. Initial contrasts: Significant effect of contrast type on accuracy. Only made errors on voice contrasts. Very low score on voice. No effect of contrast type on reaction times. Final contrasts: Trend towards effect of contrast type on accuracy. Only made errors on voice and place, with more errors on place. No effect of contrast type on reaction times.	Initial and final contrasts combined: significant effect of contrast type on accuracy. Very low score on place contrasts, also errors on voice and manner. Few errors on 2-feature contrasts. Initial contrasts: significant effect of contrast type on accuracy. Very low score on place, also many errors on voice and some on manner. No effect of contrast type on reaction times. Final contrasts: no significant effect of contrast type but accuracy low overall. No effect of contrast type on reaction times.	Initial and final contrasts combined: no difference in effect of contrast type on accuracy between words and pictures results. Initial contrasts: trend towards effect of contrast type on accuracy, with only errors on place contrasts. However, difficult to interpret as all errors were on seed/feed items. When seed/feed excluded, score at ceiling. Significant effect of contrast type on reaction times with and without seed/feed items. Slower responses to place contrasts than to all others. Significant difference from words result. Final contrasts: No effect of contrast type on accuracy, although only errors on place and voice contrasts (close to ceiling). No effect of contrast type on reaction times.

Results summary: Experiments 2 & 3 Phoneme Discrimination

Participant: TVR

	Nonwords	Words	Pictures
Match	Initial and final contrasts combined: more errors on different pairs. No difference in reaction times to initially different and same pairs. No difference in reaction times to same pairs and finally different pairs.	Initial and final contrasts combined: No effect of match on accuracy. Significantly different from nonword results. No difference in reaction times to initially different and same pairs. No difference in reaction times to same pairs and finally different pairs. Trend towards difference from nonword results.	Initial and final contrasts combined: no effect of match on accuracy. No effect of match on reaction times.
Position	No effect of position on accuracy. No effect of position on reaction times.	No effect of position on accuracy, although more errors on initial contrasts. No effect of position on reaction times.	No effect of position on accuracy. No effect of position on reaction times.
Contrast type	Initial and final contrasts combined: no effect of contrast type on reaction times, although more errors on voice and place contrasts.	Initial and final contrasts combined: no effect of contrast type on accuracy, although more errors on voice contrasts.	Initial and final contrasts combined: no difference in effect of contrast type on accuracy between words and pictures results.

	Initial contrasts: no effect of contrast type on accuracy. No effect of contrast type on reaction times, although responses appear slower for voice contrasts. Final contrasts: no effect of contrast type on accuracy, although all errors on voice and place contrasts. No effect of contrast type on reaction times.	Initial contrasts: trend towards effect of contrast type on accuracy, with most errors on voice contrasts. No effect effect of contrast type on reaction times. Final contrasts: no effect of contrast type on accuracy, although only errors on place contrasts (close to ceiling). No effect of contrast type on reaction times.	Initial contrasts: No effect of contrast type on accuracy. NB. no errors on voice. No effect of contrast type on reaction times, although responses to voice contrasts appear faster. Trend towards difference from words results. Final contrasts: no effect of contrast type on accuracy, although only errors on place contrasts. Errors not on seed/feed items, but still difficult to interpret as close to ceiling. No effect of contrast type on reaction times.